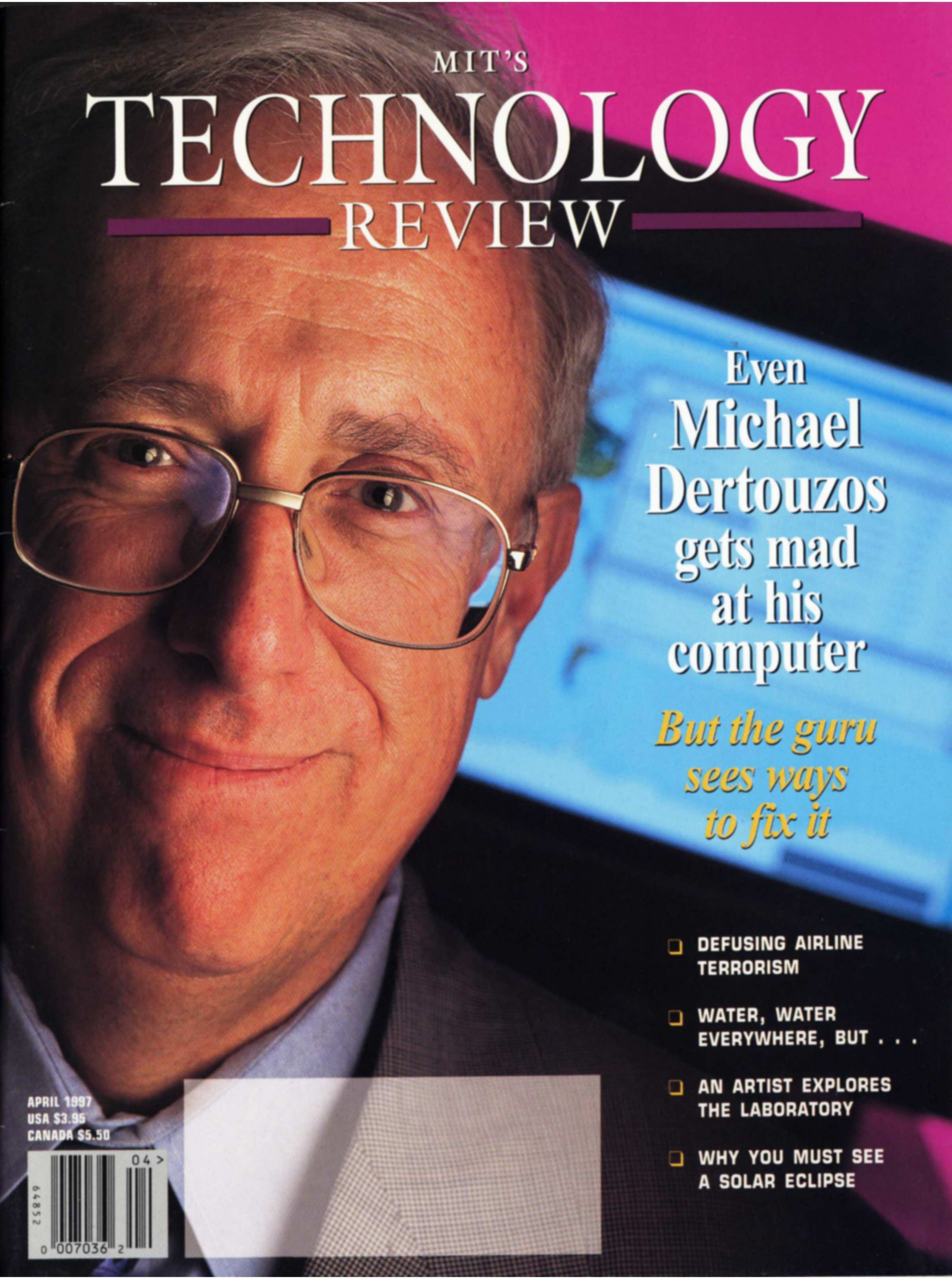
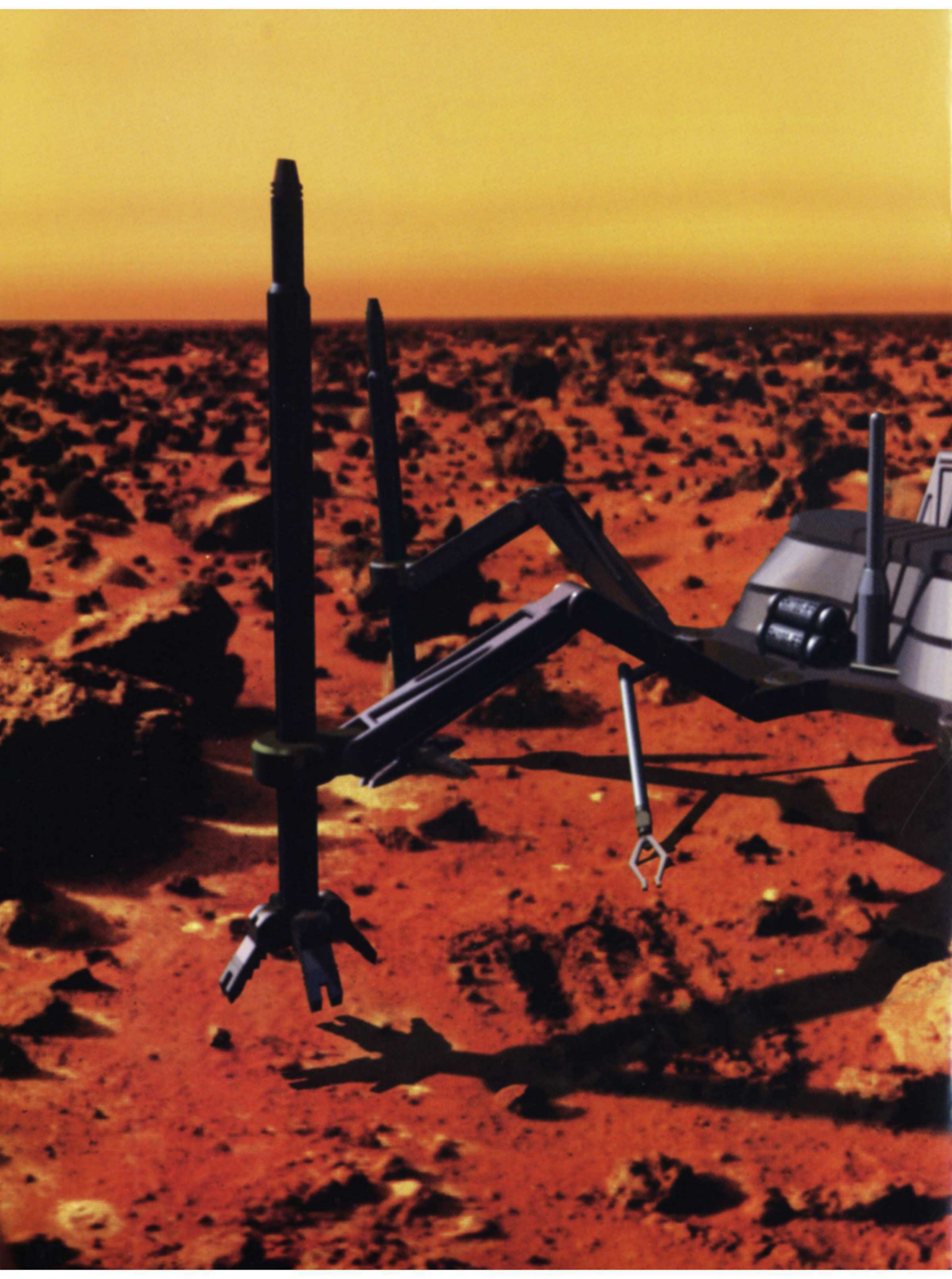

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Even
Michael
Dertouzos
gets mad
at his
computer
But the guru
sees ways
to fix it
DEFUSING AIRLINE TERRORISM
WATER, WATER EVERYWHERE, BUT . . .
AN ARTIST EXPLORES THE LABORATORY
WHY YOU MUST SEE A SOLAR ECLIPSE
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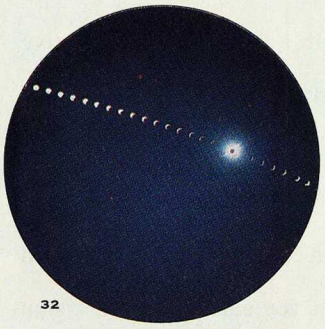
20

20 COVER STORY

CREATING THE PEOPLE'S COMPUTER

BY MICHAEL DERTOUZOS

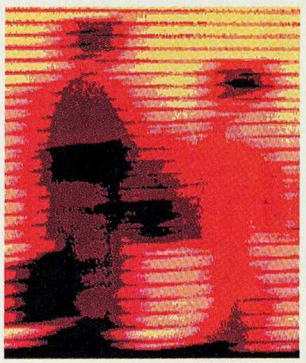
Like the frustrated TV anchorman in *Network*, the author is mad as hell and he's not going to take it anymore—in this case, the myriad ways in which the computer is misdesigned and misused. But Dertouzos, the head of MIT's Laboratory for Computer Science, proposes to do something about it. In an article adapted from his new book *What Will Be: How the New World of Information Will Change Our Lives*, he suggests ways in which designers can fulfill the technology's perennial promise of making humans more creative and productive.


32

32 WHEN THE SUN DISAPPEARS AND DOLPHINS DO BACK FLIPS

BY STEVE MIRSKY

The ancients feared total eclipses of the sun, with at least one culture performing mass human sacrifice during such extraordinary events in order to placate the gods. While our understanding of these celestial phenomena has grown, the author rediscovered firsthand the wonder they can still evoke—as well as the scientific curiosity they engender—and urges others to go out of their way to observe the total eclipse occurring early next year.


38

38 DEFUSING AIRLINE TERRORISM

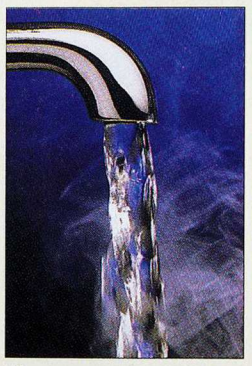
BY MARK FISCHETTI

The push is on to install sophisticated new technologies for detecting explosives at airports. But the required speed and accuracy are proving difficult to attain, and these costly systems raise difficult questions about invasion of personal privacy and the dollar value of a human life.

47 AN ARTIST EXPLORES THE LAB

BY CORNELIA HOMBURG

Photographer Catherine Wagner has created stark and compellingly beautiful images of the instruments found in major research labs. Herewith a sampling from an upcoming exhibit of her work, which helps bridge the distance between art, science, and everyday life.


54

54 DIVIDING THE WATERS

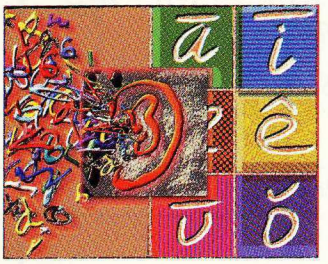
BY SANDRA POSTEL

Images of earth from space—of a world abundant with water—are as deceptive as a desert mirage. The actual amount of freshwater available on a sustainable basis to meet human needs is rapidly dwindling as population soars. Because techniques for boosting supply are prohibitively expensive, pursuing a range of water-conserving options has become essential.

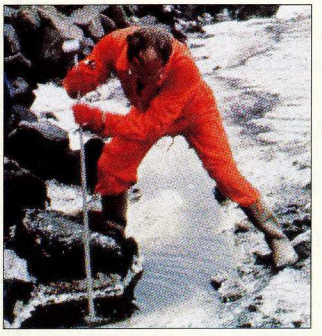
COVER PHOTO BY WEBB CHAPPELL

APRIL 1997
VOL. 100 / NO. 3

DEPARTMENTS



10


14


65

5 FIRST LINE: The Medium Is Only Half the Message

6 LETTERS

10 MIT REPORTER
Hearing What We Want to Hear

14 TRENDS
Brave New Bacterial World; Artificial Societies; Hunting the Wild Neutrino

29 FORUM
DONALD A. NORMAN
The computer and the human brain work differently. Instead of trying to force one to emulate the other, designers would do better to ensure complementarity.

63 THE HUMANE ENGINEER
SAMUEL P. FLORMAN
Digitized memorabilia such as home videos and family photograph albums can last forever. But they may well drown our descendants in accumulated megabytes.

64 THE ECONOMIC PERSPECTIVE
BENNETT HARRISON
From Seattle to Newark, nonprofit community-based organizations are now teaming up with high-tech companies to reinvigorate inner-city economic life.

65 REVIEWS
Ellen Spertus on *Escape Velocity* by Mark Dery.
Robert Crawford on *Hubble Vision* by Caroline C. Peferdon and John C. Brandt.

69 PHENOMENA: Waiting for Uncle Bill

70 TECHNOLOGY REVIEW CAREERS

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First Line

The Medium Is Only Half the Message

Technologists and storytellers: Can't we all just get along?

ENGINEERS describe the performance of new media like television or motion pictures in terms of "technical resolution"—measurements such as frame rate, spatial resolution, brightness, and dynamic range. If you design lenses or build projection systems for a living, this technical resolution is likely to be of more than passing interest—it's usually how your work is judged.

But if you're a writer or film director, you need another axis—"emotional resolution"—to describe how well you are using the technology to convey a message to your audience. Put more simply, that term measures how effectively you are communicating. Your mastery of emotional resolution is how *your* work is judged.

While it's convenient for some of us to think that one can separate the technical performance of a media-delivery system from the content itself, this is useful only to technicians. Everyone else cares about the final result when the two are inextricably merged. Most of us don't watch test patterns for fun, and moviegoers shouldn't be thinking about the theater's projection or sound systems. The engineer should design these systems so well that they are transparent to the viewer. And paradoxically, increasing the technical resolution of an imaging system can sometimes *diminish* the quality of the viewer's experience. For example, more detail in a motion picture can hurt the ability to tell a good story.

A key member of the filmmaking team is the director of photography (DP for short). The "look" of the picture is almost completely in the hands of the DP: even if the sets are great, the costumes gorgeous, the makeup amazing, and the performance captivating, if the DP is asleep at the switch, the movie will look bad. This is not desirable when thirty to a hundred million dollars are at stake.

Before starting a film, the DP's assistants can spend weeks meticulously testing every lens for such attributes as sharpness, contrast, focus accuracy, and color rendering. The name of the game is to avoid surprises when the director says "action."

I first learned how professionals guard against the deleterious emotional effects of excessive resolution while working on my first big movie: Ken Russell's *Altered States*. On the first day of shooting, I observed a ritual that was repeated for the duration. The crew (more than 100 people) arrived very early in the morning—poised, primed, and ready to make a picture. In the first few hours, the set was lit and the camera dragged out and set up. The actors and director rehearsed their performance. And then, just before the first frame (of millions to come) was shot, something peculiar happened. The camera was pointed toward the actors (this part wasn't too surprising), and the DP—a great technician and artist, Jordan Cronenweth—whispered something to his assistant, who then ceremoniously opened a serious-looking box. Out came an object called a filter, which he placed between the lens and the actor. But this was not just any filter, like a polarizer or a haze filter, which can sometimes enhance image quality, but a *diffusion* filter. This little item came from the same people, mind you, who had just spent weeks rejecting lenses with the slightest bit of flare or a tiny scratch. A lady's net silk stocking was then stretched over the lens. And as a final insult, a bit of fresh nose grease was selectively rubbed around the perimeter of the filter. (Yes, nose grease—some use Vaseline, some use hair spray, but many of the Greats use nose grease.) We were now, he announced, ready to shoot.

In less than a minute, these adjustments had reduced the performance of state-of-the-art optical equipment to something less than what you would expect from a ten-dollar disposable camera. But Jordan hadn't lost his mind; he was just doing his job of compelling visual storytelling. Trust me, you don't want to pay good money to go to your local movie theater to see an unfiltered close-up of your favorite actor. You would be able to count hairs and skin pores and come to realize that movie stars look just like we do at six in the morning. Your concentration on the film's *story* would be disrupted. A technically exemplary job of capturing excessively high-resolution images would produce bad storytelling.

Later during filming, I watched Jordan paint shadows on the walls (this is not metaphorical—he used paint), adjust the lighting to produce reflections and glare, create lots of darkness, add camera shake, and otherwise insult the optical sensibilities of the camera system, all in the service of good storytelling. Incidentally, I thought *Altered States* was a great-looking film.

When all is said and done, both technical resolution and emotional resolution are essential, and anyone who expects to realize the best results from communications media for living, breathing people needs to understand both.

Thus multimedia designers and storytellers each require fluency in both the technical and emotional arts. But these groups of professionals are often worlds apart and have little basis for mutual understanding, communication, and experimentation. If you don't believe this, just spend a day surfing the World Wide Web for beautifully designed, experientially rich sites.

So here's an idea: we might begin modifying the curricula in our colleges to reflect this diversity. Can you think of a great art *and* science school? I can't. Isn't there room for at least one MIFAT (Massachusetts Institute of Fine Arts and Technology)?

I am absolutely convinced that if we can successfully combine the skills of our great storytellers with those of our creative technologists—for example, those who are building and refining the Internet—the results will be amazing. At the moment, most of these folks still aren't talking to each other, and usually aren't even aware that they should. If we get this right, future generations won't remember the period to come as the Information Age but rather as the Storytelling Age. ■

—BRAN FERREN

BRAN FERREN is executive vice-president for creative technology/R&D at Walt Disney.

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Letters

REINVENTING THE WHEEL

We very much enjoyed "Hubs, Struts, and Aesthetics" by Sidney Perkowitz (*TR November/December 1996*). We were surprised to learn that wheel design was once left totally up to engineers, who, in our experience, are not particularly concerned with aesthetics. Perhaps this explains the existence of custom-wheel manufacturers.

One could go even further into this interesting topic by discussing the various design differences that seem to be culturally or ethnically driven. For example, why do German designers seem to prefer lug screws rather than lug nuts? Leave it to the eminently proletarian and practical company Renault to produce designs that require only three fasteners per wheel. And, of course, one shouldn't forget the British cars that use only one fastener per wheel, the knock-off lug that has been universally adopted on racing cars.

Some will even remember the thoughtful Chrysler engineers who perhaps took design too far and made cars with right- and left-hand threaded studs and lug nuts for use with the wheels on the corresponding sides of the car. There are surely many other examples of design taking form and function beyond the experience of the common man.

JEFF AND CORRINA MOSSBERG
Tampa, Fla.

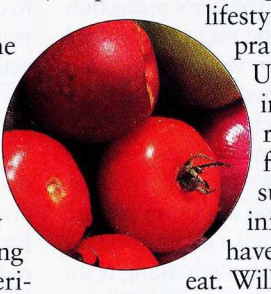
I enjoyed "Hubs, Struts, and Aesthetics." However, I found two instances where "bicycle" was used sloppily. First, a caption on page 58 identifies the kick-propelled running machine invented by Karl von Drais in 1817 as the first bicycle. The term "bicycle" was introduced nearly 50 years later to distinguish the new pedal-powered two-wheeler from its by-then obsolete predecessor, the running machine.

Perhaps more objectionable is the author's claim that "later still, spokes of iron or wood showed up on early steam engines, and then on automobiles and bicycles." Wooden and iron spokes were applied to bicycles well before they were used on automobiles. The original bicycle, patented by Pierre Lallement in 1866, had wooden spokes. By 1869, superior wire wheels for bicycles had been developed.

DAVID V. HERLIHY
President
Lallement Memorial Committee
Boston, Mass.

KNOWING WHY THEY CHOOSE THE FOODS THEY DO

As Ellen Ruppel Shell demonstrates in "Food Warrior: A Profile of Walter Willett" (*TR November/December 1996*), Willett's efforts to establish a relationship between eating, exercise, and other lifestyle parameters are praiseworthy. A look at U.S. food patterns during the past century reveals how much the food industry, farm subsidies, and misinformed do-gooders have influenced what we eat. Willett's research is critical in developing future nutritional and related lifestyle recommendations.



I would agree, however, with Samuel Shapiro's remarks in the article questioning the accuracy of nurses' food-intake records, which are the basis of Willett's research. Many studies confirm that most of us significantly underestimate how much we eat, and that we develop selective amnesia, especially when asked to recall our junk-food consumption. Eating habits also change markedly when individuals are stressed, but what we eat when angry or depressed is rarely re-

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corded accurately in a food-frequency table. Even the best-intentioned eater will desert his or her nutritional principles for pizza or potato chips when feeling emotionally besieged.

We need to know more about what people eat. But to develop strategies that will really convince people to improve their eating patterns, we also need to know why they choose the foods they do.

JUDITH J. WURTMAN
Research Scientist
Department of Brain and Cognitive Science
MIT

KEEPING THE RED PLANET IN PERSPECTIVE

In "Mars on a Shoestring" (*TR November/December 1996*), Robert Zubrin presents a compelling scenario for getting to Mars. However, a multiyear mission that relies on untested technologies and unflown vehicles is not going to happen; the expense and risk of catastrophic failure for the crew are just too great.

We should first practice vehicle landings and launches, habitat construction, and production of consumables and propellants on and around the moon. Granted, the moon is not Mars: physical and chemical differences will not permit the complete training and testing of every Mars-bound system, crew included. But the moon is a convenient platform for learning how to reach Mars in an orderly fashion.

EDWARD MCSWEEGAN
Crofton, Md.

In one sentence, Zubrin dismisses robotic exploration of Mars in favor of a human one. Please don't sell robotic technology short—particularly when doing so adds time, cost, and risk. Why doesn't the author just admit to being a romantic and get on with it?

Furthermore, the whole idea of gaining private funding for a Mars venture does not hold water. Before proposing it, Zubrin should have passed the prize component by some industry leaders for reaction.

WIL MATHEWSON
Bonsall, Calif.



While the human impulse to avoid mundane challenges is likely to keep Zubrin's vision afloat, we may finally be getting wise enough to inquire about the trade-offs.

I confess I eat strawberries that come from out of state. But will I want to pay more for stainless steel if the chromium comes from Mars? What, other than precious metals and gems, could be worth importing over such distances? Given our national struggle with budgeting for our non–Mars-related priorities, I believe that Mars exploration does not deserve one taxpayer dollar that could otherwise feed, vaccinate, or educate a child right here on earth.

GEORGE EMMERT
Huntington, Ind.

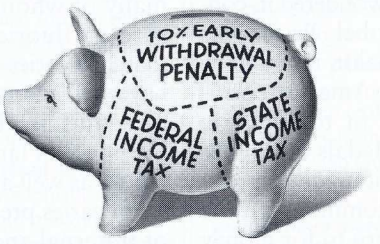
I was happy to read Zubrin's proposal for a low-cost visit to Mars. We need a large-scale goal that will link us with other nations in a common enterprise. Despite the sad outcome of Russia's recent Mars probe, I believe efforts to explore our spatial frontier should continue full force.

C. MALLORY GRAVES
Lynchburg, Va.

GIVING SOFTWARE A SCRIPT

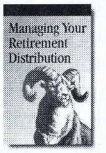
Heartfelt thanks to Joseph L. Lazzaro for presenting an important yet relatively unknown issue in "Toward Software Both Seen and Heard" (*Forum, TR October 1996*). As a deaf computer

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user, I have become increasingly frustrated with the multimedia-software industry. Of the hundreds of products available, few provide a comprehensive text option. Those that do are often aimed at elementary-school kids. This means that deaf adults cannot use many of the hottest products on the market.

Owing to copyright laws, software manufacturers cannot simply provide users with a program script. A practical solution would be a universal module or program that converts sound effects and dialogue into text, perhaps inside a small window. A similar concept, known as closed-captioning, has been extremely successful in the television and video-media industries and could just as easily be integrated into computers and their applications. Just like any product, software should always be developed with the needs of every user in mind.

HARRIET E. WINTERMUTE
Los Angeles, Calif.

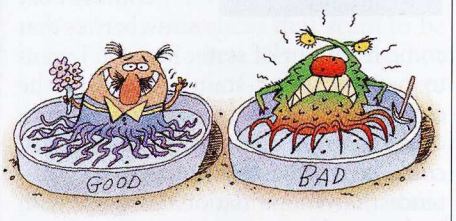
INDUSTRIAL SUGAR DADDIES

After reading "Medals Are Nice, but" (*TR November/December 1996*) by Robert M. White, I wondered if, considering that the Nobel Prize was endowed by an industrialist, it would be too much to hope that American businesspeople would see fit to similarly endow the National Medals of Science and Technology. I find it mildly depressing but unfortunately common that the first sugar daddy we turn to for money is the faceless federal government. That habit is reinforced when commentators of White's caliber also propose it. What has happened to the national record of industrial philanthropy that built the rural libraries and museums we still enjoy today? It will be interesting to see what kind of legacy the Bill Gateses of the world will build and leave for future generations.

KENNETH DURHAM
Houston, Tex.

IT'S WORTH SPIT

As Jane E. Stevens points out in "Oral Ecology" (*TR January 1997*), *mutans streptococci*, the most cavity-inducing oral organisms, have all the advantages: rapid generation time, mutations that have endowed them with an extensive range of virulence factors, and a special relationship with sucrose that must have been made in bacterial heaven. Many have paid for the sweet life through their teeth. Although fluoride has leveled the playing field, we need to remember that nature has endowed our oral fluids with a plethora of protective systems that help



us maintain the integrity of the hard and soft tissues against the bacterial hordes. That saliva is the key mechanism is shown when a severe shortage of saliva, known as xerostomia, manifests itself in rampant caries.

Case-control studies comparing the fortunate caries-resistant adults (CR), many of whom never had early exposure to fluoride, with age- and sex-matched caries-susceptible (CS) controls have yielded insights into host protective mechanisms. The high rate of caries resistance in families of the study population, as well as historical familial studies of caries prevalence and comparison of fraternal and identical twins reared together as well as apart, strongly suggests a genetic component to caries resistance. Prominent among the possible genetic pathways of resistance are salivary components that directly, or by their products, buffer or neutralize plaque acids, elevate plaque pH, and affect the bacterial ecology of plaque. For example, histidine-rich and arginine-rich peptides, which modify plaque pH, are significantly higher in the CR. Also, submandibular saliva of CR promotes significantly greater aggregation and less adhesion of streptococci than CS in standardized in-vitro tests. Both phenomena could contribute to low counts of *mutans streptococci*.

The enamel pellicle—the acquired skin of our teeth that is derived mainly from saliva—is critical to protecting us against the loss of tooth surface. While enamel cannot renew itself once teeth are fully formed and erupted, the enamel pellicle is a continually renewable insoluble film that limits acid diffusion and mineral egress. Pellicles in the CR are significantly less permeable to acids than the CS.

The large array of protective molecules in saliva could conceivably become part of host augmentation strategies. With the therapeutic properties of leech saliva and bat saliva already being commercialized, why not do the same with human saliva?

IRVINE D. MANDEL
Professor Emeritus of Dentistry
School of Dental and Oral Surgery
Columbia University
New York, N.Y.

"Oral Ecology" runs counter to the recent trend of encouraging human compatibility with nature. While microorganisms are universal and natural, significant tooth decay isn't. The author is pushing medicine instead of a diet of whole grains, legumes, vegetables, and fruits that might better solve the problem.

CHARLES G. SANTORA
St. Petersburg, Fla.

COLLEGE KNOWLEDGE

Bringing college freshmen up to speed on library resources might best be accomplished without the special course advocated by editor Steven J. Marcus in "Ask the Librarian" (*First Line, TR November/December 1996*). Careful planning and coordination among the faculty could ensure that every student, during his or her first year, receives assignments that require the use of every major resource under the library's roof, including the Internet. These students would complete their first year confident that they were ready for the next three.

RONALD D. LINDOW
Pittsburgh, Pa.

TECHNOLOGY UPDATE

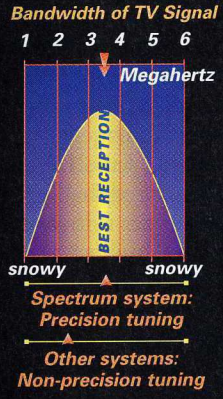
Fifteen years of microelectronic research makes conventional antennas a thing of the past!

This little box uses your home's electrical wiring to give non-subscribers, cable subscribers and satellite users better TV reception on local broadcast networks!



Technology corner

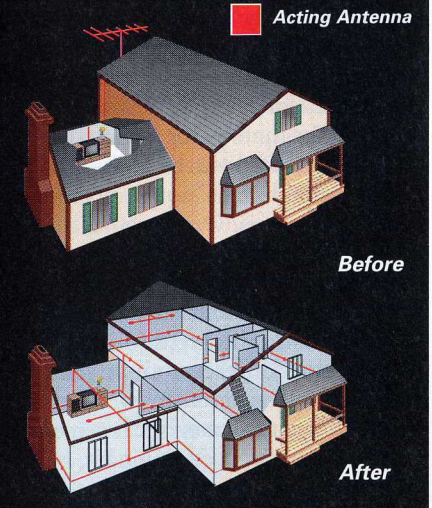
Why don't conventional antennas work as well as the Spectrum?



- When TV signals are tuned at the TV channel's center frequency, optimum tuning has been achieved.
- Other antennas can't offer center frequency tuning like the Spectrum Antenna can. They only offer such tuning up to the edge of the center frequency. As a result, your TV picture remains snowy.

How does Spectrum use a home's electrical wiring as an antenna?

Believe it or not, the Spectrum Antenna simply "activates" the giant antenna that already exists in your home. Essentially, it uses all of the wiring throughout your home's walls and ceilings to make an antenna as large as your house for unbelievably clear reception of local broadcasting.



Until recently, the only convenient way to guarantee great TV reception was to have cable installed or place an antenna on top of your TV. But who wants to pay a monthly cable fee just to get clear reception, or have rabbit-ear antennas that just don't work on all stations? Some people just aren't interested in subscribing to cable. Or they may live in an area where they can't get cable and TV-top antennas aren't powerful enough. And what about those people who have cable or satellite systems but still can't get certain local stations in clearly?

Now, thanks to fifteen years of microelectronics research, a new device has been developed that is so advanced, it actually makes conventional antennas a thing of the past. It's called the Spectrum Universal Antenna/Tuner.

Advanced technology. Just imagine watching TV and seeing a picture so clear that you'd almost swear you were there live. Just plug the Spectrum Antenna into a standard AC outlet and plug your TV into the Spectrum. You can remove the unsightly clutter of traditional TV-top devices gathering more dust than television signals. Get ready for great reception. Your TV will display a sharp, focused picture thanks to Spectrum's advanced "Signal Search" and "Fine Tuner" controls.

Uses your home's electrical wiring. The Spectrum Antenna is a highly sophisticated electronic device that connects into a standard wall outlet. The outlet interfaces the Spectrum Antenna with the huge antenna that is your home wiring network. It takes the electrical wiring in your house or apartment and turns it into a multi-tunable, giant TV reception station which will improve your TV's overall tuning capability. The results are incredible. Just think how much power runs through your home's AC wiring system—all that power will be used to receive your local broadcasting signals.

How it works. Broadcast TV signals are sent out from the local broadcast station (ABC, CBS, NBC, etc.). They interface with your home's AC power line system, a huge aerial antenna network of wiring as large as your home itself. When the Spectrum Antenna interfaces with the AC line, the signal is sent to its signal processing circuit. It then processes and separates the signal into 12 of the best antenna configurations. These specially-processed signals route themselves into 12 separate circuits. The Spectrum Antenna includes a 12-position rotary tapping switch, the "Signal Switch" control, which gathers 12 of the best antenna configurations.

The "Signal Search" offers varying antenna configurations for the user to select from the best signals of all those being sent. The signal then passes through the Spectrum Antenna's special "Fine Tuner" circuit for producing crisp, clear reception.

Rural areas. If you live in a rural area you may need to enhance the incoming signal—most rural areas signals are weak, making them harder to fine tune. The "Gain Booster" is a high-frequency signal booster designed to increase the output level of the signal entering your television. It delivers a 10-fold greater signal which will bring richer color and a noise-free picture. By using the "Gain Booster," all of the Spectrum's fine tuning controls will function better, giving the Spectrum Antenna a stronger signal to fine tune. It also works in conjunction with your outdoor antenna.

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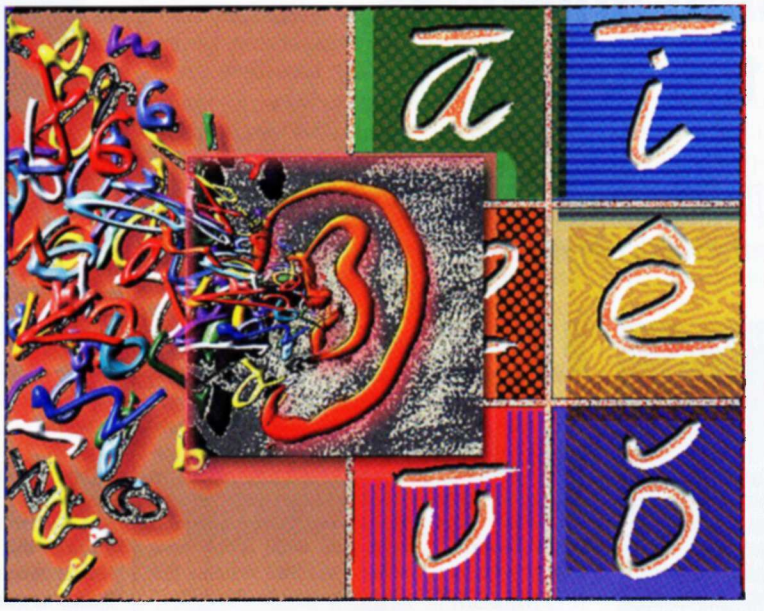
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MIT Reporter

Hearing What We Want to Hear



Say *pet*. Now say *pat*. Hear the difference? Of course. Now say one halfway between the two. Can't do it? Or can you just not hear that you're doing it?

Since the 1960s, speech scientists have known that although it's possible to produce sounds that are acoustically halfway between two recognized vowels, speakers never hear them halfway—they perceive them as one or the other. Even when people listen to a series of synthetic vowels, progressing in equal acoustic steps between that in, say, *pat* and *pet*, they hear a series of *pats* followed by a series of *pets*. Now researchers at MIT and elsewhere are building theories to explain this phenomenon, called categorical perception, so they can better understand how we hear speech. Such research could have implications for learning second languages, and might even help computers understand us better.

It's well known that our ability to discriminate between different versions of the same vowel isn't uniform for all gradations of that vowel. Some are harder to distinguish from their neighbors than others. Researchers think that variations in our sensitivity to small acoustic differences between speech sounds may help us categorize and interpret the sounds of our native languages.

Louis Braida, a professor in the Sensory Communication Group at MIT's Research Laboratory of Electronics (RLE), set out to map native speakers' sensitivity to English vowels. When he asked subjects whether they could distinguish between slightly different vowels, he found that discrimination ability is highest not between the most perfect example of each vowel and its immediate neighbors, but between examples near the category boundaries, where one vowel is on the verge of being perceived as a different vowel. In earlier research, Braida and his colleague Nathaniel Durlach had discovered a similar pattern in people's sensitivity to variations in loudness. Subjects found it harder to discriminate pairs of faint tones than pairs of loud tones, as expected. But they got a boost in sensitivity when comparing subtly different examples at the extremes of a set of tones, around the loudest or the softest examples. They had been the least sensitive to variations square in the middle of the range.

Braida theorizes that people categorize sounds by estimating how far each is, acoustically, from what he calls "perceptual anchors"—memorable stimuli located at the edges of a range of examples. To discern where a particular vowel sound falls in relation to the extremes, he says, "you gauge the difference from each anchor with a 'perceptual ruler' that measures in units of a just-noticeable difference." The farther the vowel is from an anchor, however, the blurrier the ruler becomes and the less accurately the sound is perceived. For Braida, the imperfection of the ruler corresponds to the limitations of our basic auditory resolution ability.

Categorical perception may also be influenced by our native languages, according to Patricia Kuhl, a professor in the Department of Speech and Hearing Sciences at the University of Washington. Using almost 100 synthesized versions of a particular vowel—the long-*e* sound, as in *Pete*—Kuhl asked subjects to rate each sample on a scale from one to seven. A certain region of the vowel space, a "sweet spot" if you will, consistently got the best ratings. Kuhl calls this region the prototype. Like Braida, she discovered that listeners' sensitivity to differences is lowest in this middle region and highest at the edges of the range. She attributes this variation to a "perceptual magnet effect" in the middle region. "The prototype appears to act like a magnet for other sounds in the category," says Kuhl. "It seems to perceptually 'assimilate' nearby sounds, making it difficult for people to hear any differences between the prototype and these other sounds."

Nature Versus Nurture

Kuhl believes that the special status of prototype vowels becomes impressed on our minds early in life. Research performed on American and Swedish babies by Janet Werker, a professor of psychology at the University of British Columbia, suggests that, by the age of 10 or 12 months, infants lose the ability to hear distinctions that do not occur in their native languages. On the basis of such research, Kuhl concludes that categorical perception has a learned component: people with different native languages have different prototypes for their vowels, and thus different boundaries and different regions of sensitivity.

To what extent categorical perception is learned, as opposed to innate, has yet

ILLUSTRATION: SUSAN LEVAN

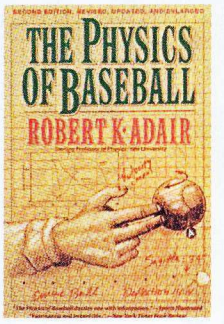
to be determined, but knowing more about how the phenomenon arises could conceivably result in better speech recognition systems. An advantage that categorical perception seems to bestow on humans is that it helps us reduce the effect of variability in speech. "Listeners," Kuhl says, "must be able to categorize, or 'render equivalent,' the sounds produced by different people, even though the sounds are very different acoustically." But variability is a problem for speech recognition systems: strong accents, for example, can render certain words unintelligible to machines. Kenneth Stevens, who heads the Speech Communication Group at MIT's RLE and whose research interests include speech recognition, believes computers could be programmed to pay less attention to details that humans don't notice. "The design of speech-recognition systems," he says, "should take into account that the human auditory-brain system is inherently sensitive to certain attributes of sounds in speech and not sensitive to others."

Understanding the delicately layered structure in our ability to perceive speech could also yield insights into the teaching and learning of foreign languages. The same categorical perception that numbs us to certain phonetic differences in our native tongues can reduce our sensitivity to crucial distinctions in other languages. As Kuhl has written, "The phonetic categories of the native language are analogous to a perceptual sieve. . . . The phonetic units of the newly acquired language must pass through the sieve, making distinctions in the new language imperceptible." This may be why speakers of Japanese, for example, have trouble hearing the *l/r* distinction in English: the prototype to which they have become attuned falls somewhere between the two consonants. Explicit training in hearing such distinctions may help second-language learners pick up a new accent more efficiently. And further research might give us a better idea of how well adult immigrants can be expected to learn new languages.

—*Karen Chenausky*

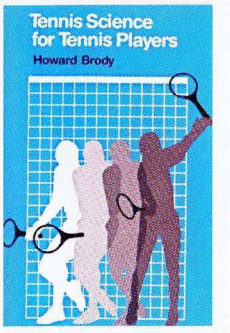
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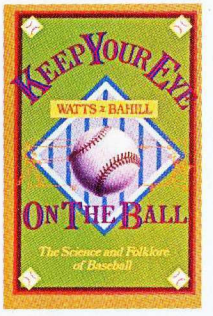


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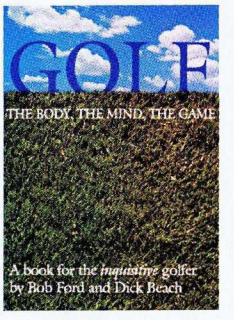


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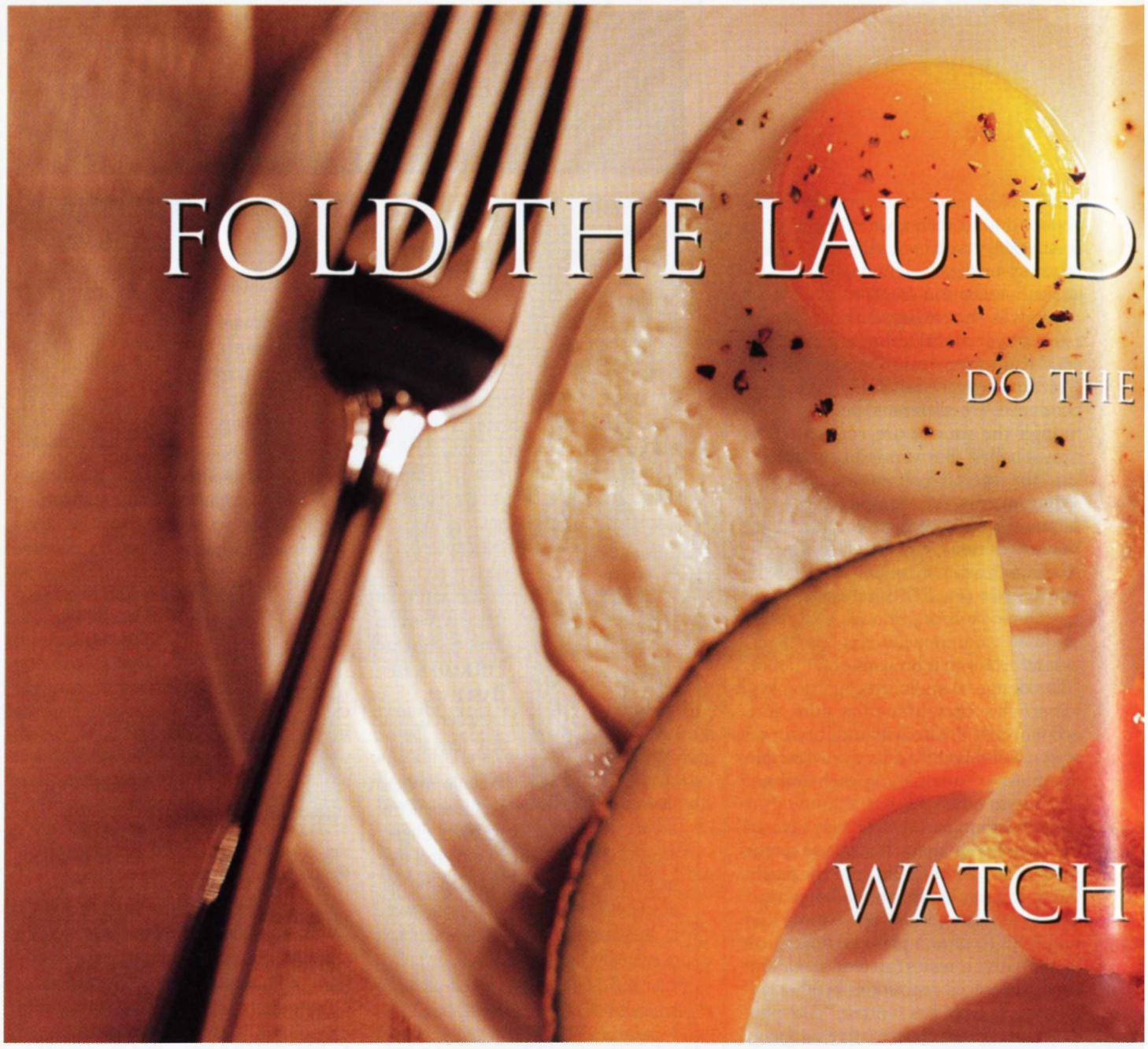
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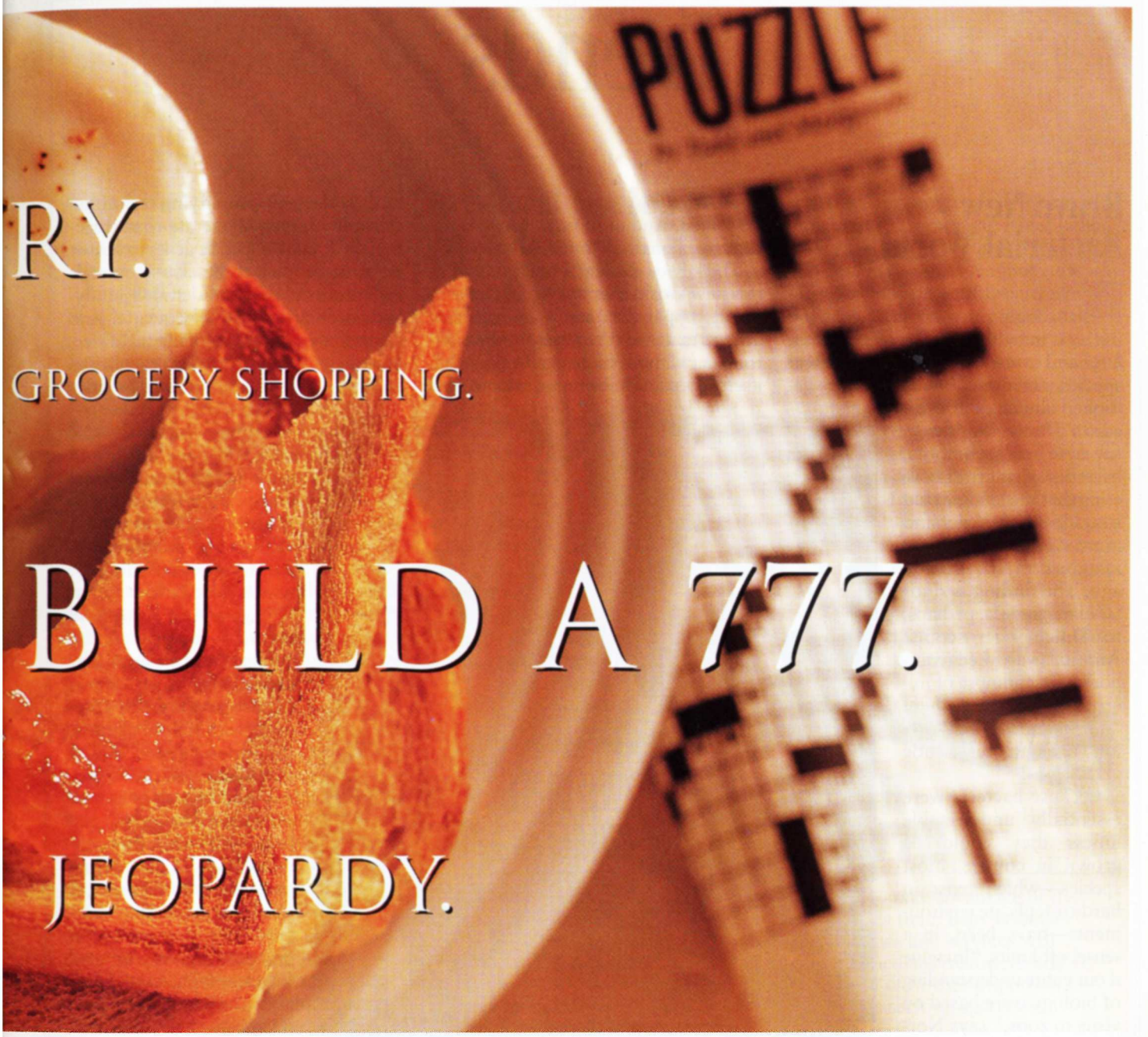
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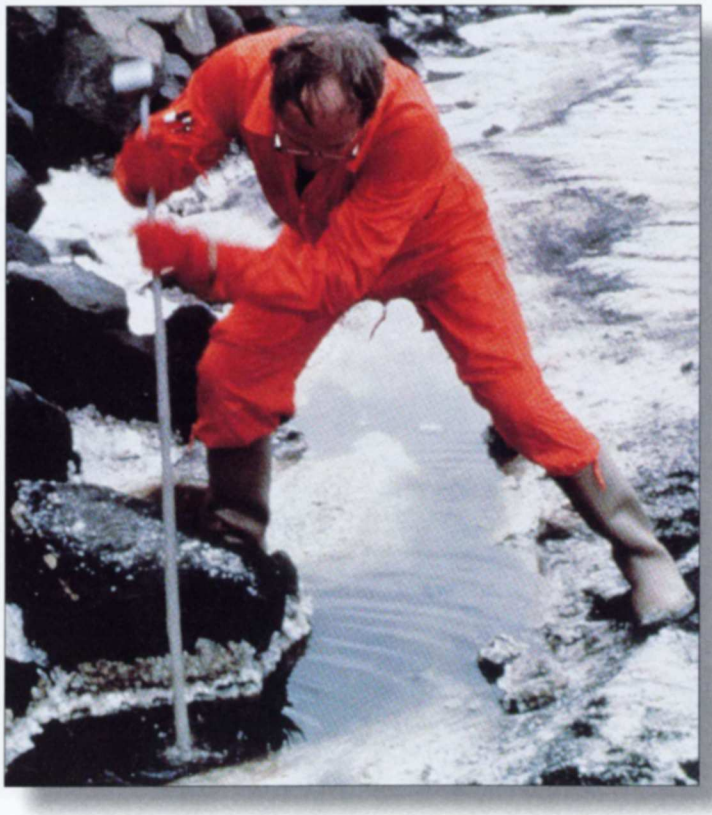
Brave New Bacterial World

Despite 300 years of peering through microscopes, growing bacteria in culture, and screening soil, air, and water for new microbial species, scientists have clearly overlooked much of life on earth. Thanks to powerful new research tools, bacteriologists are discovering that the living world is suddenly far bigger and more complex than they imagined even a decade ago. The finding is similar in magnitude, perhaps, to Dutch microscopist Antonie van Leeuwenhoek's first glimpse of microbes—he called them "animalcules"—cavorting beneath his crude glass lenses.

Because bacteria were essentially undetectable unless they could be grown in culture, most species—which exist in hard-to-replicate environments—have been, in a sense, off limits. "Imagine if our entire understanding of biology were based on visits to zoos," says Norman R. Pace, a biologist at University of California, Berkeley. "That is analogous to our situation with respect to understanding the microbial world."

Melvin Simon, chair of the department of biology at the California Institute of Technology, estimates that "about 99 percent of the bacteria out there can't yet be grown" in laboratory culture dishes. That's because scientists often can't determine the precise combination of conditions—including oxygen, temperature, and light—that microbes need and because it's difficult to simulate these requirements all at once to make them happy. About 6,000 species of microorganisms have been formally described. And until now, he says, the rest have remained "invisible" to us.

The key to gaining a first glimpse at this new world was in learning how to isolate, amplify, and study an organism's genetic material directly from the environment without culturing the organism itself. By using molecular instruments that selectively pick out a bacterium's highly specific genes from a broth of DNA, scientists can now quickly identify new organisms, explore their properties, and determine their kinship to organisms that are already known.



Scientists with novel research tools are discovering an abundance of strange new bacteria just about everywhere they look, even in harsh environments. Here bacteriologist Karl Stetter of the University of Regensburg in Germany collects samples from a saline hot spring at Lake Affal, Djibouti, Africa.

Prominent among the new molecular tools is the gene-amplifying technique called PCR, the polymerase chain reaction. PCR allows specific genes to be isolated and copied endlessly, so enough become available for detailed study, such as of a gene's DNA sequence. And it's in the sequence—actually the differences in sequences from one organism to another—that the microbes' identities can be seen.

Along with PCR, the new tools include rapid sequencing technology, quick computer processing of gene-sequence data, and increasingly accurate electrophoresis technology, which electrically separates genes in a gel or fluid according to size.

One of the major analytical targets of such work is the ubiquitous RNA (ribonucleic acid) in ribosomes, the little rounded bodies that living cells use as protein-building devices. All cells have ribosomes, and because the RNA they contain differs slightly from one species to the next, it serves as a reliable marker—sort of a molecular dog tag—that can be used for identifying, classifying, and analyzing each new microbe.

The surprising finding is that everywhere researchers apply these new techniques, they are encountering strange new bacteria, in abundances and diversities that no one really anticipated. For example, as Paul Dunlap, an associate scientist at the Woods Hole Oceanographic Institution in Massachusetts, explains in the Woods Hole publication *Oceanus*, the sea's microbial life is so incredibly abundant that in some cases organisms occur "in extraordinarily high numbers, up to about 100 billion per milliliter" of seawater. In fact, organisms less than 2 microns in diameter found living in the sea are so abundant they account for 95 percent of the mass of all

PHOTO: RECOMBINANT BIOCATALYSIS

forms of life in the world's oceans.

Sedimentary soils, even the ancient mud deposited on the deep-sea floor, are also vastly alive with microorganisms. Recent drilling into the floor of the Sea of Japan, for example, brought up samples—from layers of sediment buried 500 meters deep—containing millions of organisms in every gram of soil.

New Realms

The findings suggest that even a tiny sip of water, or a small sample of soil, carries enough bacteria—most of them previously unknown—to keep squads of researchers busy for years. "There are new genes, new enzymes, and new functions we don't know anything about," Simon notes, and the data are piling up too fast to be analyzed in detail. "They (the microbes) even have some different kinds of cell membranes," suggesting that whole new realms of biology are there to be explored.

Since each organism has its own genes, characteristic biochemistry, structure, and behavior, the industrial potential is huge. Each species harbors between 1,000 and 5,000 genes, and for the most part their biochemical properties are still unknown. So it is likely that new enzymes, foods, drugs, chemicals, materials, and processes will be discovered. Bacteria that can live in the hostile environment of hot springs, for example, have yielded special enzymes that perform beautifully at high temperature, which could be of use in chemical processing. Also, Pace says, some microorganisms make substances that adhere to surfaces in water that is almost boiling, which could be valuable in certain manufacturing operations.

In evolutionary terms, Simon notes, it should come as no surprise that so many different kinds of bacteria exist, even in places where they once seemed unlikely. After all, "for 3 billion years the world was populated by bacteria" and probably very little else. So these single-cell organisms have had far more time to evolve than most other creatures on earth.—*ROBERT COOKE*

Artificial Societies

Notwithstanding the folk wisdom that history repeats itself, the rise and fall of civilizations is an experiment that runs only once, which makes the job of those who study society inherently challenging. Indeed, the inability to conduct repeatable, verifiable experiments on social phenomena has caused some in the physical sciences to denigrate the social sciences as "soft."

Well, the social sciences just got a little harder. Researchers at the Brookings Institution in Washington, D.C., have devised a sophisticated software program to study societies *in silico*, allowing economists, demographers, and other social scientists to rerun history, as it were, changing single variables and testing the results. Their so-called "artificial societies," the program's developers say, offer unique insights into issues ranging from racial segregation to mass migration, and may just revolutionize the way social scientists pursue their research.

The road to such artificial societies was laid down in 1953, when mathematician John von Neumann invented self-replicating automata. These cellular automata, as they are also known, consist of a lattice of cells with specific values that change according to fixed rules for computing a cell's new value based on its current value and the values of its immediate neighbors. Von Neumann found that, when left to their own devices, cellular automata naturally formed patterns, reproduced, even "died."

The first attempt to apply such techniques specifically to social science occurred in the 1970s, when economist

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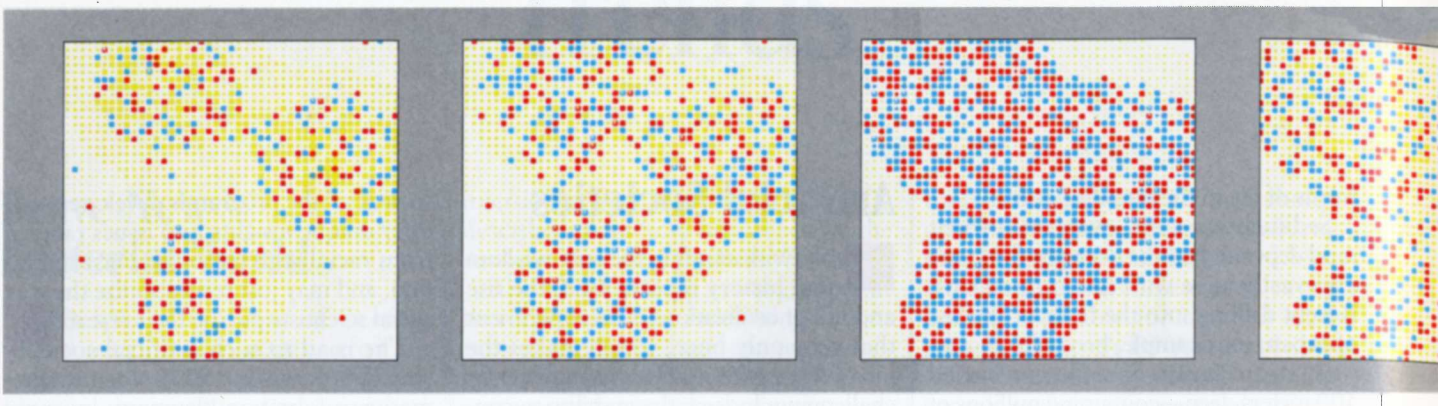
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Artificial-life programs can be used to study real-world social phenomena, such as baby booms. In Sugarscape, red females and blue males proliferate when given plenty of space and yellow food. But overcrowding causes resources and populations to drop sharply, only to build up gradually and repeat the cycle.

Thomas Schelling created an artificial world using nothing more than pennies and dimes that he moved around a checkerboard according to simple rules. Schelling's study showed, among other findings, how even slight preferences for living and working with one's own kind can result in extreme segregation.

Though primitive by today's standards, both efforts revealed how social patterns develop of their own accord out of the discrete interactions of individuals. Yet so-called artificial life did not take off until the 1980s with the giant leap in computing power and the advent of object-oriented programming, a technique that allows programmers to define objects, or entities, in terms of specific characteristics and actions.

Known to aficionados as Alife (see "What's It All About, Alife?", *TR* April 1996), these sophisticated artificial-life programs allow agents to interact directly with every other agent and the environment, rather than just with their immediate neighbors, say Brookings Alife developers, social scientist Joshua M. Epstein and computer modeler Robert Axtell. For example, in Sugarscape, as the researchers whimsically dub their most intensively studied artificial society, agents have some traits that are fixed and others that vary depending on their location and interactions. In a typical Sugarscape model, an agent's vision, sex, and metabolic rate are set for life, while its wealth, cultural identity, marital status, and health can change.

The agents behave according to simple rules. In a typical run of Sugarscape, in which sugar represents food, agents follow the mandate, "Look around as far as you can, find the site richest in food, go there and eat it." Agents thrive if they secure enough food to meet their metabolic needs and "die" if they cannot.

A remarkable range of phenomena emerges from the interaction of these simple agents, according to Epstein and Axtell. For instance, the ecological principle of carrying capacity—that any given environment can support only a finite population—quickly becomes apparent, they say. When "seasons" are introduced, migration occurs. Tribal formation, cultural transmission, trade, hibernation, and combat have also been observed and studied.

All this would be just programmer's play if it didn't have real-world applications. But applied aspects are just what Epstein and Axtell are after. Their work is part of the 2050 Project, a joint venture of Brookings, the World Resources Institute, and the Santa Fe Institute, an independent research organization, to identify and achieve conditions for a sustainable global system in the next century. Epstein and Axtell are using Sugarscape and other artificial-society models for everything from evaluating economic theories to "growing" a silicon version of an actual human society.

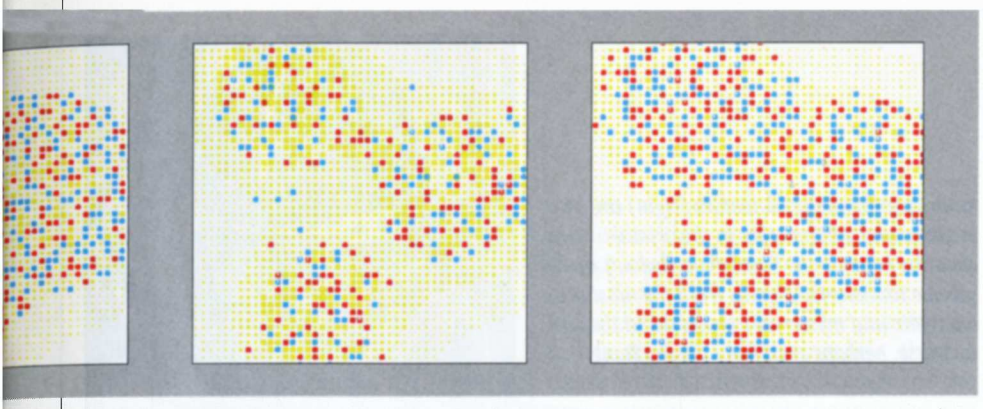
In one experiment, the researchers tested theories about the distribution of wealth. Ever since Vilfredo Pareto, a nineteenth-century mathematical economist, first quantitatively described highly skewed distributions of income and wealth, economists have held that such stratifications are a given in human societies. Epstein and Axtell set out to test the theory in Sugarscape, where agents, like people in the real world, continually accumulate wealth (in the form of sugar). In run after run, under myriad variations of rules and environments, the law held up, Epstein says; indeed, it proved the first qualitative similarity between simulated and actual human societies.

The theory has challenged other commonly held theories. Classic laissez-faire economic theory, for example, holds that, if left to their own devices, markets allocate goods and services efficiently and reach a state of equilibrium—in which supply equals demand—without any help from the government. Classical mathematical models, which use so-called "orthodox" agents with infinite lives and fixed preferences, uphold that theory, as does Sugarscape when it uses such agents. But when Sugarscape's agents are made to look and act more like real people—that is, are given finite lives and evolving preferences—the computerized market never reaches equilibrium. "This challenges the efficiency of unregulated markets at a very deep level," Epstein argues.

The ability to turn particular behaviors "on" or "off" has made for other compelling discoveries. When the team added the social institution of inheritance to Sugarscape, by allowing agents to pass on whatever sugar they still owned at "death" to their offspring, they found that agents' visual abilities—to find the goods necessary for survival—on average actually went down over time. "That makes sense because inheriting sugar buffers you against natural selection," Epstein says. "You might not be endowed with tremendous genetics, but because you're born rich, you don't feel the selection pressure as much."

In another study, the Brookings researchers studied a genetically challenged population—one with both poor

COMPUTER IMAGES: ROBERT AXTELL, JOSHUA EPSTEIN



vision and high metabolism—that, in run after run, died out. They discovered that when a single variable was altered—the agents were allowed to trade—the society not only survived, but even rebounded, ultimately sustaining long-term oscillations in population. Axtell explains that much of this population, which needed both sugar and spice to survive, began dying out as before. But those who had only sugar began trading with those who had only spice. As a result, a few individuals prospered from the trading and began reproducing with abandon until the population grew too large and the cycle repeated itself.

Such experiments can be useful for testing theories about social conditions in the real world. Suppose you have a theory of international relations. "Deploy your little states on a space, give them the rules and regulations you think apply," says Epstein, "and see if you can generate the end of the Cold War, or the formation of NATO, or whatever you like."

Epstein and Axtell have been conducting one such study of how extraordinary social phenomena can form out of the interactions of individuals. Working with archeologists at the Santa Fe Institute, with which Epstein and Axtell are also affiliated, and the University of Arizona, the researchers are attempting to replicate the actual history of the Anasazi, a Native American people who lived in the Southwest from the first to the fourteenth centuries. "The idea is to take little cyber Anasazi, place them under the same environmental conditions that applied to the real Anasazi, and see if we can devise simple rules under which simulated evolution matches true evolution," Epstein says.

It's not a purely academic exercise. Archaeologists have long wondered why the Anasazi suddenly disappeared around 1350. Epstein and his colleagues first simulated the environmental factors that were relevant at the time, including climatic changes, but found that these alone could not account for the plunging population and the Anasazi's eventual departure. They are now introducing cultural elements such as clan formation and land-inheritance practices to determine their effect.

Epstein and Axtell chose the Anasazi because they wanted to model a society that was relatively simple, well-understood (from archeological studies), and more typical of societies in the developing world, where overuse of resources is occurring apace and where sustainable-development experts feel their efforts will bear the most fruit.

Agent-based computer simulations may just change fundamentally how social scientists go about their work. Many in the field have bemoaned the artificial decomposition of social science into separate disciplines, including economics, cultural anthropology, politics, and demography. Epstein and Axtell imagine artificial societies like Sugarscape as the first step toward a new "transdiscipline" that subsumes these various fields. Such an all-encompassing method would enable college professors, for example, to teach an interdisciplinary kind of social science. "An assignment might be to design the following artificial world and come in with a movie of its evolution," says Epstein. "Students might make connections they wouldn't otherwise think about—that, in fact, they're trained *not* to think about."

—*PETER TYSON*

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Hunting the Wild Neutrino

The forbidding Antarctic ice cap has become a new Mecca for astronomers looking to take advantage of the continent's many months of darkness and pristine skies. Yet perhaps the most revolutionary astronomy project now under way at the South Pole plans to make use not of its clear views but its surprisingly clear ice.

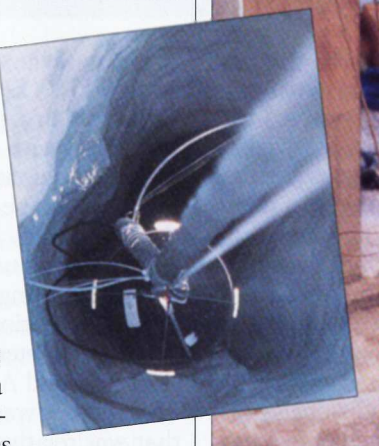
For four years, an international team of scientists has been drilling holes up to 2 kilometers deep into the ice in order to build Amanda, the Antarctic Muon and Neutrino Detector Array. By spring, the principal investigators say, they should obtain their first indication of whether the premise behind their project is valid: that it is possible to do astronomy based not on light or any other form of electromagnetic radiation but on neutrinos.

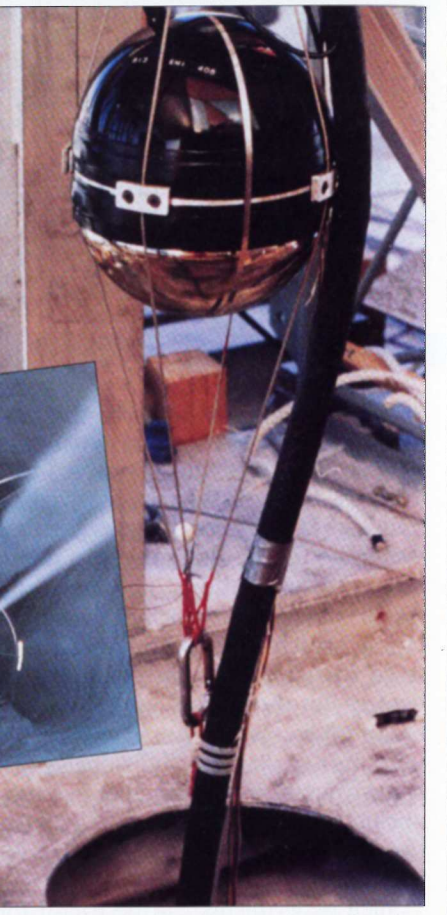
If they are right, the repercussions would be enormous. Neutrino astronomy could give scientists a view straight to the heart of some of the most violent and energetic processes in the universe, including quasars and active galactic nuclei (distant galaxies believed to be powered by massive black holes), as well as the sources of mysterious gamma ray bursts and perhaps even the universe's origin in the Big Bang.

What makes neutrinos such a good subject for astronomy is that unlike visible light or other forms of radiation they zip through the universe virtually unimpeded. Produced as a byproduct of the nuclear fusion that occurs at the heart of every star, they have no electric charge and—as far as anyone can tell so far—no mass. So if astronomers could detect neutrinos and measure their energy levels they could learn more about what goes on in those stars.

Neutrino detection is also important for studying high-energy sources such as active galactic nuclei. The powerful gravitational pull of these objects and the interstellar dust and gas surrounding them prevent most other forms of energy from escaping. It is as if astronomers, even with radio telescopes and instruments that capture other wavelengths of radiation, were viewing them through a dense fog. Researchers expect that Amanda will see through this turbulence to reveal a sky dotted with heretofore unknown sources of intense energy, thus opening a new chapter in astronomy.

An array of neutrino detectors (right) are buried some 2 kilometers in the crystal-clear ice beneath the South Pole (below) to receive undistorted signals from the most energetic and mysterious processes in the universe, perhaps even from the Big Bang.





The only problem with neutrinos is that the very property that makes them such valuable sources of information also makes them devilishly difficult to detect. The earth is constantly bathed in a flood of neutrinos, yet astronomers have no way of detecting them directly. Instead, they look for evidence that high-energy neutrinos have collided with the atomic nuclei of surrounding matter. When collisions occur, they give off muons—negatively charged particles that are like electrons but have more than 200 times the mass. These muons give off a bluish light called Cherenkov radiation that cascades away from the crash site like waves from the bow of a boat.

Fortunately, the direction of muons aligns closely with the direction of the neutrinos that produced them. So a three-dimensional Cherenkov light detector, such as that provided by Amanda's array of detectors buried beneath the South Pole, could not only confirm that high-energy neutrinos passed through, but also identify their trajectory with better than a 1-degree resolution: good enough to pinpoint their sources in the sky.

An early indication of the promise of muon detection came on February 24, 1987, when astronomers at an observatory in Chile spotted a new supernova. At the same time, neutrino detectors in Kamioka, Japan, and Cleveland, Ohio, registered a sudden flurry of activity, confirming that high-energy neutrino showers are associated with violent astronomical events.

Encouraged by these findings, the U.S. Department of Energy funded DUMAND, the Deep Underwater Muon and Neutrino Detector, which attempted to drop detectors into the deep ocean off Hawaii to hunt for neutrinos in December 1993. But technical problems stalled the project, which was eventually canceled last fall.

Another deepwater project is now under construction by European and U.S. scientists in the Mediterranean Sea. Yet, as Amanda scientists point out, the problem all oceanic detectors face is in filtering out the noise of background radiation from radioactive potassium, which is present in small amounts in ocean water, as well as from biolumines-

PHOTOS: ROBERT M. MORSE; UNIVERSITY OF WISCONSIN

cent bacteria and higher organisms, not to mention the dangers to the instruments from currents and storms.

Conversely, Antarctic ice, which is essentially pure freshwater containing no such contaminants, produces virtually no background radiation. Moreover, once detectors are frozen in the ice, they will not be disturbed.

Amanda research teams, including those from the University of Wisconsin, the University of Delaware, the University of California campuses at Irvine and Berkeley, the Lawrence Berkeley Laboratory, and Swedish universities in Stockholm and Uppsala, originally placed some 80 detectors a kilometer deep in the ice. But initial tests showed that at that depth the ice, which fell as snow some 18,000 years ago, had bubbles that interfered with the transmission of the Cherenkov radiation emitted by the muons. The team later found that the bubbles disappeared at around 1,500 meters, so in subsequent years detectors were placed at depths of around 2 kilometers. The faint bluish light travels more than 300 meters and should be more easily picked up by the detectors, 400 of which by February are scheduled to be distributed in a cylindrical pattern with a radius of 60 meters and a depth of 2 kilometers.

Faint Traces

For a project with such grand hopes, the technology it uses is fairly simple. The detectors are commercial photomultiplier tubes packed inside thick glass globes. They are like "flashlights in reverse," explains Francis Halzen, an astrophysicist at the University of Wisconsin-Madison and one of the leaders of the project. The tubes can detect the faintest traces of light given off by neutrino collisions, amplify them more than 100 million times, and transmit the signals back to the surface as electrical pulses through coaxial cables for analysis.

To drill the holes for the strings of detectors, scientists use a technique borrowed from glaciologists called hot-water drilling. The rig uses a device similar to a massive shower head that gushes scalding water to melt the ice. As the ice melts, the water is recirculated, heated, and fed back down the hole. Since the drill is steered by gravity, its fall is straight, deviating less than 1 meter over a kilometer. Because of the ice's natural insulating properties, the hole doesn't refreeze for about four days, giving the crews enough time to deploy the strings of detectors.

The detectors are already hard at work. They record some 25 events per second, but nearly all are too weak to be of interest to Amanda scientists. The researchers are looking for the signature of neutrinos that have traveled all the way through the earth to arrive at detectors from below, figuring that the earth will filter out the radiation from less energetic sources and leave only the signature of high-energy neutrinos. In fact, Halzen says the detectors have picked up such readings, which the collaborators believe are traces of the high-energy neutrinos the project is being built to detect.

To measure actual energy levels more precisely, Halzen makes use of the very air bubbles in the ice that originally seemed to pose a problem. It turns out that the bubbles gather and scatter light in a predictable fashion. By measuring how far and in what direction the light emitted by excited muons scatters throughout the detector array, scientists can calculate the energy levels of incoming neutrinos.

In his public talks, Halzen likes to point out how astronomy has succeeded in exploring radiation arriving from space at wavelengths spanning 18 orders of magnitude, from languid radio waves to intense gamma rays. Neutrinos—which are emitted by radiation with wavelengths up to eight orders of magnitude smaller than gamma rays—are in essence a messenger that astronomers hope to use to describe that radiation. It's hard to know what energy sources astronomers would find at that level, but, Halzen says, "it's inconceivable that there's nothing out there."

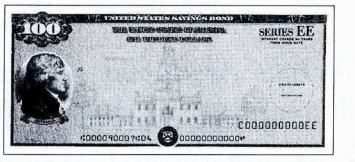
Ironically, one fear of the Amanda scientists is that their findings might put them too far ahead of the rest of the astrophysics community. As Halzen says, if no other instrument is able to replicate Amanda's observations, "I'm afraid one day we'll see all these wonderful things and no one will believe us."

Scientists familiar with the project, however, are expecting a better fate. "Our experience in astronomy in the last 50 years is that when a new technique for observing the universe is applied, nature always turns out to have surprises in store for us," says John Bahcall, a physicist who studies neutrinos at the Institute for Advanced Study in Princeton, N.J. "What we observe," he says, "is not what we expect to observe."

—*MARK WARD*

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Creating the Pe

One of the nation's foremost computer scientists, exasperated by the unfriendliness of today's computer systems, suggests what designers can do to make machines serve human needs—rather than the other way around.

BY MICHAEL L. DERTOUZOS



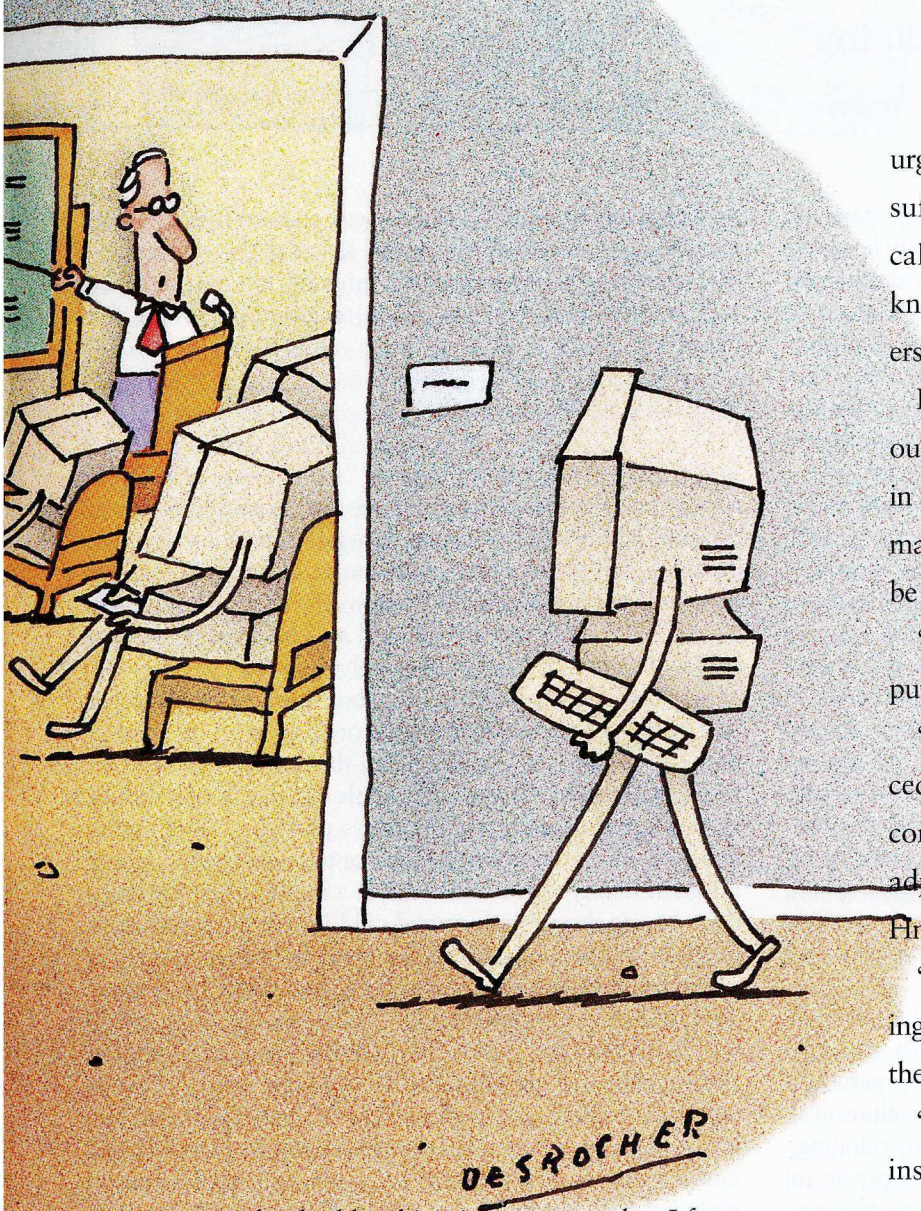
IT is a few days before Christmas. I am out shopping at a well-known upscale department store in the Greater Boston area. I take nine items to the cash register. The cashier passes her magic wand over each package to read the bar code, and the impact printer rattles away as it prints a description and price for each item. I am getting ready to pull out my credit card when the woman turns to the cash register beside her and, horror of horrors, starts keying in the exact same information manually, reading the numbers off each package in turn.

She is on package number six when I clear my throat conspicuously and, with the indignation of a time-study specialist, ask her why in the world she is duplicating the work of the bar-code reader. She waves me to silence with the authority of one accustomed to doing so. "Please, I have to finish this," she says politely. I tell her to take her time, even though my muscles are tightening up and my brain is engaging in vivid daydreams of punitive acts.

She finishes the last package, ignores my pointed sigh, reaches for a pencil, and . . . starts all over again! This time she is writing in longhand on the store's copy of the receipt a string of numbers for every pack-

ILLUSTRATIONS BY JACK DESROCHER

pple's Computer



age. I am so shocked by this triple travesty that I forget my anger and ask her in true wonder what she is doing. Once more she waves me to silence so she can concentrate, but then obliges: "I have to enter every part number by hand," she says. "Why?" I ask, with a discernible trembling in my voice. "Because my manager told me to," she replies, barely suppressing the urge to finish her sentence with the universal suffix "stupid." I could not let this go. I called for the manager. He looked at me knowingly and said with a sigh, "Computers, you know."

I told him that this looked a bit more serious than that, and he proceeded to explain in slow, deliberate phrasing that the central machine didn't work, so a duplicate had to be entered by hand.

"Then, why enter it at all into the computer?" I ventured hopefully.

"Because it is our standard operating procedure, and when the central machine comes back, we should be in a position to adjust our records for inventory changes." Hmm.

"Then why in the world is she both keying in the numbers *and* entering them with the bar-code reader?" I countered.

"Oh. That's the general manager's instruction. He is concerned about our computer problems and wants to be able to verify and cross-check all the departmental entries."

I quietly walked out, stunned.

After I got over my shock at the absurd waste of time this store's procedures caused for the cashier—and me—I began to marvel at how the great promise that computers would improve human productivity is

PRODIGY seized control of my computer, informing me it would take a few "moments" to download some new software. I could do nothing to stop it from "helping" me in its own murderous way.



more easily discussed than implemented. Indeed, the topic of whether computers are raising human productivity has generated a great deal of controversy. Technology detractors will point to such encounters and say, "See, computers don't help us." And it's true that information technology does hurt productivity in some cases; it takes longer to wade through those endless automated phone-answering menus than it does to talk to a human operator. If technology is not used wisely, it can make us less productive instead of more so.

But computers can also be incredibly helpful. Used properly, they help ring up prices faster, track inventory, and handle price changes. Productivity will rise in the Information Age for the same reason it did in the Industrial Age: the application of new tools to relieve human work.

Some people dismiss productivity concerns, arguing that computers make possible things we couldn't do otherwise. Certainly that is true, as the World Wide Web, special effects in movies, and credit cards have shown us. But to ignore the computer's fundamental ability to help humans do their brain work is at best perverse and at worst irresponsible. Productivity is the yardstick by which socioeconomic revolutions are measured. That was the case with plows, engines, electricity, and the automobile. If there is to be a true information revolution, computers will have to repeat the pattern with information and information work.

As we try to anticipate how computers might be used in the twenty-first century we are bombarded with unparalleled confusion and hype—a faster Web/Internet, network computers, intranets, cyberspace, 1,000 video channels, free information, telework, and much more. To my thinking, this future world can be described simply and crisply as an "information marketplace," where people and their interconnected computers are engaged in the buying, selling, and free exchange of information and information work.

Many issues surround the information marketplace: the technology of its underlying information infrastructures; its uses in commerce, health, learning, the pursuit of pleasure, and government; and the consequences of these new activities for our personal lives, our society, and our history. Here we will focus on a small but crucial aspect of this rich ensemble—ensuring that tomorrow's information marketplace will help us in our eternal quest to get more results for less work.

MICHAEL L. DERTOUZOS is the director of MIT's Laboratory for Computer Science. The article is adapted from his book What Will Be: How the New World of Information Will Change Our Lives, *recently published by HarperEdge, an imprint of HarperCollins.*

MISUSED AND ABUSED

Let's begin by examining a series of "faults"—ways in which computers are misused today because of either technological or human foibles. The first step toward improving our productivity will be to correct these faults. Next, we'll explore how to begin automating human work through computer-to-computer exchanges. The final and perhaps most vital step will be to make computers truly easier to use.

❖ *The additive fault:* The ridiculous duplication of effort that I ran into at the department store happens often and in many different settings. We'll call this failure the additive fault, because in these cases people are doing everything they used to do before computers plus the added work required to keep computers happy or to make people appear modern. In anybody's book, this is a mindless productivity decrease. It should be stopped cold in whatever setting it raises its ugly head. And while we are at it, let's recognize this particular problem is not caused by technology but by our own misuse of technology.

❖ *The ratchet fault:* Some time after my encounter with the cashier, the same gremlins that seem to run ahead of me to set up challenging situations must have surely visited the airline clerk I encountered at Boston's Logan Airport. When I handed him my ticket to New York and asked him to replace it with one to Washington, D.C., he said, "Certainly, sir," and bowed to his terminal, as if to a god. As a seasoned observer of this ritual, I started recording his interactions. Bursts of keystrokes were followed by pensive looks, occasionally bordering on consternation, as with hand-on-chin he gazed motionless at the screen, trying to decide what to type next. A full 146 keystrokes later, grouped into 12 assaults demarcated by the Enter key, and after a grand total of 14 minutes, I received my new ticket.

What makes this story interesting from a productivity perspective is that any computer-science undergraduate can



design a system that does this job in 14 seconds. You simply shove your old ticket into the slot, where all its contents are read by the machine. You then type or speak the "change" command and the new destination, and you get the revised ticket printed and shoved back in your hand. Because 14 minutes is 60 times longer than 14 seconds, the human productivity improvement with such a box would be 60 to 1, or 6,000 percent!

Something is terribly wrong here. People run to buy a new computer because it is 20 percent faster than the one they have, and we are talking here about a 6,000 percent improvement. So why aren't the airlines stampeding to build this box? For one thing, if they did this for every one of the possible requests, they would have to build a few thousand different boxes for each terminal. All right then, why don't they reprogram their central computers to do this faster? Because that would cost a billion dollars. Why? Because the airlines have been adding so many software upgrades and changes to their systems that after 20 years they have built up a spaghetti-like mess that even they cannot untangle. In effect, they cannot improve their system without starting from scratch.

We'll call this the ratchet fault of computer use because it's like a ratcheting tire jack: every time a new software modification is added the complexity of the system rises, but it never comes down unless a precipitous event, like a total redesign, takes place. This problem is more a consequence of inadequate technology than of unsound human practice. If we had a software technology that could let us gracefully update our systems to suit our changing needs while maintaining their efficiency, then we wouldn't be in this bind.

❖ *The excessive-learning fault:* One-tenth of my bookshelf is occupied by word-processing manuals. Add the manuals for spreadsheets, presentations, and databases, and they easily fill half a shelf. Because I use graphics and do a bit of programming, I need a few more manuals. This brings the total length of my computer guidebooks to one EB—one (printed) Encyclopaedia Britannica. We'll simply call this the excessive-learning fault—the expectation that people will learn and retain an amount of knowledge much greater than the benefits they'd get from using that knowledge. Imagine requiring people to digest an 850-page manual in order to operate a pencil. We laugh at the thought, but we accept it readily in the case of a word-processing program. I have little doubt that the first half of the twenty-first century will be spent getting rid of fat manuals and making computers much easier and more natural to use.

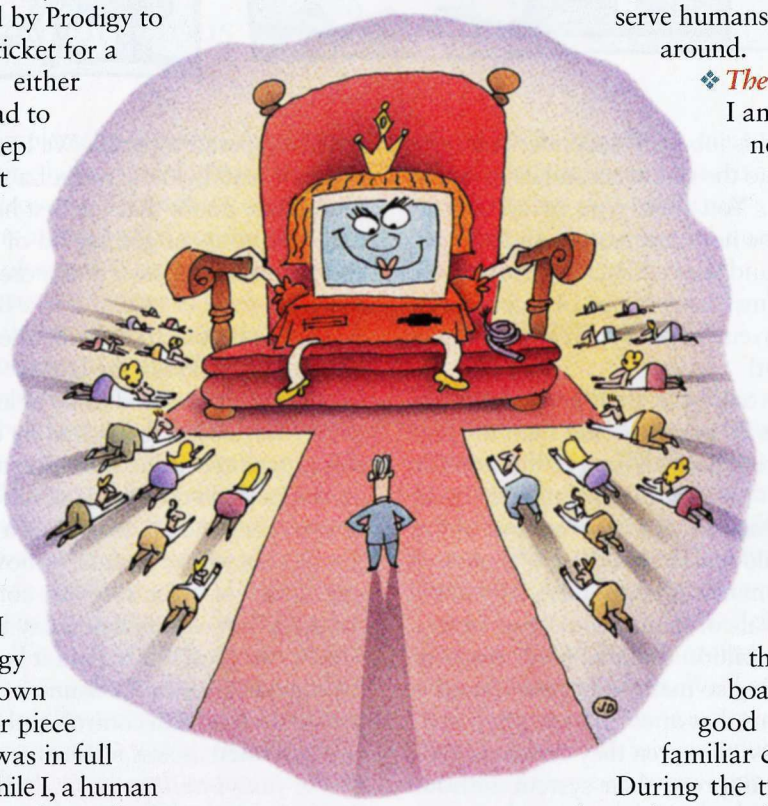
❖ *The feature-overload fault:* Bloated is perhaps a more accurate adjective to describe the feature-packed programs hitting the market in the late-1990s. Vendors do so in part to cover their bets and to be able to charge higher average prices. Buyers are fascinated by the potential uses of their computers and value their prerogative to command their machines to do thousands of different things. Of course, in practice they end up doing only a few tasks and forget what features they have bought or how to use them. A top-selling "suite" of office software comes on a CD-ROM or 46 diskettes that require half a day to load into your machine. This is not productive. And it is caused by us, not technological weaknesses. Consumers and corporate executives should declare birth control on the overpopulation of excessive and often useless features.

❖ *The fake-intelligence fault:* My car has a fancy phone that was advertised as "intelligent" because when it makes a phone connection it automatically mutes the volume of the car radio to ensure a quiet environment. I found this feature delightful until one afternoon when I heard a good friend being interviewed on the radio. I immediately called a mutual friend so she could listen along with me over the phone and share in the excitement. This, of course, was impossible, because the phone muted the radio and I couldn't override it. Welcome to the fake-intelligence fault. It crops up in many situations where a well-meaning programmer puts what he or she believes is powerful intelligence in a program to make life easier for the user. Unfortunately, when that intelligence is too little for the task at hand, as is always the case, the feature gets in your way. Faced with a choice between this kind of half-smart system and a machine with massive but unpretentious stupidity, I would opt for the latter, because at least then I could control what it could do.

As users striving to improve our productivity, we must always ask whether a new program offers enough value through its purported intelligence to offset the headaches it

will inadvertently bring about. And suppliers of these ambitious programs should endow them with a Go Stupid command that lets users disable the intelligent features.

❖ *The machine-in-charge fault:* It is 2:00 a.m., and I just got home. My Swissair flight from Logan was canceled because of trouble in the motor controlling the wing flaps. Some 350 passengers whose plans were thwarted were bombarding every available clerk at the airport. I abandoned that zoo, rushed home, switched on my computer, and tried to connect to the Easy Sabre do-it-yourself airline-reservation service offered by Prodigy to search for an alternative ticket for a morning flight out of either Boston or New York. I had to find out before going to sleep if this was possible. But before I had a chance to enter a single keystroke, Prodigy seized control of my screen and keyboard. It informed me that to improve my system's use of its online services, it would take a few moments (meaning a half-hour minimum) to download some improved software.



There was nothing I could do to stop Prodigy from "helping me" in its own murderous way. A meager piece of anonymous software was in full control of this situation, while I, a human being, was pinned against the wall. Meanwhile, I knew that with each passing minute, another of those frantic nomads at the airport would take another of the rapidly vanishing seats on the next morning's few flights. I gladly would have used software that was several generations old to get my job done sooner. I felt I was drowning in shallow surf from a stomach cramp while the lifeguard on the beach was oblivious to my screams because he was using his megaphone to inform me and all the other swimmers of improved safety procedures.

This is exactly the same fault that requires precious humans to spend valuable time executing machine-level instructions dispensed by hundred-dollar automated telephone operators, with their familiar "If you want Marketing, please press 1. If you want Engineering . . ." A good part of this machine-in-charge fault must be attributed to human failure in allowing such practices to continue without objection, but programmers must also take some of the blame. They often deliberately commit this fault because it's simpler, therefore cheaper, to program a computer to interrogate the user and not let go until all questions have been answered in one of a few fixed ways than to allow the user to do any one of several things with the assurance that the computer will pay attention.

Of course, interactions controlled by the machine are not always undesirable. A mistaken command by you to erase everything inside your computer should not be casually executed. However, 95 percent of the overcontrolling interactions on the world's computers don't involve such grave situations. The sooner these software crutches vanish and the user is given control, the sooner machines will serve humans rather than the other way around.

❖ *The excessive-complexity fault:* I am at my office, it is almost noon, and I discover with considerable panic that I forgot to retrieve from my home computer the crucial overheads I need for an imminent lunch meeting. No sweat. I'll call home and have them shipped electronically to my office. As luck would have it, though, the only one home is the electrician, but he is game. "Please turn the computer on by pushing the button on top of the keyboard," I say. He is obviously a good man, because I hear the familiar chime through the phone. During the two minutes the machine takes to boot up, the electrician asks why the machine doesn't come on instantly, like a light bulb.

I refrain from telling him that I share his consternation. For three years I have been trying to interest sponsors and researchers in a project that would address this annoying business in which a human respectfully begs permission from a computer's software to turn the machine on or off. Instead, I explain that the machine is like an empty shell and must first fill itself with all the software it needs to become useful. "Okay," I say, "pull down the Apple menu and select the Call Office command," which I had providentially defined some time back. He complies, and I hear my home modem beeping as it dials my office modem. On the second ring I hear the office modem next to me answer. We are almost there, I muse hopefully.

"Do you see the message that we are connected?" I ask.

"Nope," he responds. Another minute goes by and he reads me an alert message that has appeared on my home computer's screen. I know what happened. The modems latched correctly and can send signals to each other but for some unknown reason the software of the two machines

cannot communicate. I ask him to hold while I restart my machine. Like many people, and all computer professionals, I know that restarting with a clean slate often solves problems like this one, even though I have no idea what actually caused the problem.

As I guide the electrician through rebooting my home computer, I get angry, because these problems would be reduced if my office computer were calling my home machine rather than the other way around. But my home machine has only "remote client" software, meaning that it can call out but cannot receive calls. This distinction between clients and "servers" is a residue of corporate computing and the time-shared era's central machines, which dispensed lots of data to the dumber terminals. The distinction must vanish so that all computers, which I'd coin clervers, can dish out and accept information equally, as they must if they are going to be able to support the distributed buying, selling, and free exchange of information that will take place in the information marketplace.

When my home machine has again booted up, we go through the modem dance once more, and this time the software latches. I ask the electrician to select the Chooser command and click on the Appleshare icon and then to click on the image of my office machine. Now he needs my password, which I give him promptly. He reports activity on his screen that I interpret as success. I tell him how to locate the precious file I need and send it to me. In two and a half more minutes the overhead images arrive safely in my machine. I thank the electrician profusely and send the images to my printer, now filled with blank transparency sheets, and I've got them. I arrive at the meeting 30 minutes late.

Why couldn't I simply give my home computer in one second a single command like "Send the overheads I created last night to my office" and have them arrive three minutes later? Fellow techies, please don't tell me it can be done with a different kind of machine or a different operating system, macros, agents, or any other such tools, because I know and you know better. This simple act just cannot be carried out easily and reliably with today's computers.

As system designers we must begin the long overdue corrective actions against the excessive-complexity fault by simplifying options, restricting them, and, most important, reversing a design point of view rooted in decades-old habits. We should tailor computer commands and options to user's needs, rather than tailoring them to existing system and subsystem needs and expecting users to obediently adapt. We must do for computer systems what we have done for cars—get away from giving people controls for the fuel mixture, ignition timing, and the other subsystems, and give them a steering wheel, a gas pedal, and a brake for driving the car.

I have tried for years to interest sponsors and researchers in a project that would eliminate the need for people to essentially beg permission from a computer's software just to turn the machine on or off.

ELECTRONIC BULLDOZERS

One of the biggest roadblocks to building an effective information marketplace is the inability of interconnected computer systems to easily relieve us of human work. This is because today's networked computer systems have no way of understanding one another, even at a rudimentary level, so they can carry out routine transactions among themselves. Yet the potential for automating information work is huge—one-half of the world's industrial economy comprises office work, suggesting how huge this new socioeconomic movement could be. To offload human brainwork, we must develop tools that let computers work with one another toward useful human purposes. I call the tools that will make this possible "automatization" tools to distinguish them from the automation tools of the Industrial Revolution that offloaded human musclework.

Today we are so excited by e-mail and the Web that we plunge in with all our energy to explore the new frontier. If we stop and reflect for a moment, however, we will realize that human productivity will not be enhanced if we continue to use our eyes and brains to navigate through this maze and understand the messages sent from one computer to another. Imagine if the companies making the first steam and internal combustion engines of the Industrial Revolution made them so that they could work together only if people stood beside them and continued to labor with their shovels and horse-drawn plows. What an absurd constraint. Yet that is what we do today—expend a huge amount of human brainwork to make our computers work together. It's time to shed our high-tech shovels and build the electronic bulldozers of the Information Age. That's what the automatization tools are all about.

Achieving some basic degree of understanding among different computers to make automatization possible is not as technically difficult as it sounds. But it does require one very difficult commodity: human consensus. One simple way to achieve automatization is to use electronic forms (e-forms), where each entry has a pre-agreed meaning that all participating computers can exploit through their programs.

Suppose that I take 3 seconds to speak into my machine the command, "Take me to Athens next weekend." My machine would generate the right e-form for this task and ping-pong back and forth with the reservation computer's e-form before finding an acceptable date and class and booking the flight. Since it would have taken me 10 minutes to make an online reservation myself, I could rightfully brag that my productivity gain was 200 to 1 (600 seconds down to 3 seconds), or 20,000 percent!

Thus we can imagine that in the information marketplace, common interest groups will establish e-forms to specify routine and frequently recurring transactions in their specialty, whether those entail buying oranges wholesale or routing around x-rays among different medical departments. If the members of such a group can agree on an e-form, especially one that represents a laborious transaction, then they will achieve substantial automatization gains. Computer programs or people interested in doing that kind of business would be able to look up the agreed upon e-form and use it in their computer, toward the same gains but with much less effort.

Quite a few computer wizards, and people who are averse to standards, believe that common conventions like e-forms resemble Esperanto, the ill-fated attempt to create a universal spoken language among all people. They argue that attempts at shared computer languages will suffer the same ills. Instead, they advocate that the only way our computers will get to understand each other will be by translating locally understandable commands and questions among their different worlds, just as people translate between English and French.

This argument is faulty because shared concepts are required even in translating among different languages. Whether you call an object *chair* or *chaise,* it is still the thing with four legs on which people sit. It is that shared concept base, etched somehow in your brain, that makes possible a common understanding of the two different words in English and French. Without it, no amount of inter-conversion can lead to comprehension, simply because, as in the case of computers, there is nothing in common on either side to be comprehended.

If we can form a consensus within and across specialties concerning the most basic concepts computers should share, then even if we end up with different languages and dialects, software developers will be able to write programs and ordinary users will be able to write scripts that install useful computer-to-computer automatization activities—searching for information on our behalf, watching out for events of interest to us, carrying out transactions for us, and much more.

GENTLE-SLOPE SYSTEMS

Automating computer-to-computer transactions and fixing problems in present computer systems are good steps toward making computers and the information marketplace serve us. But designing systems that are inherently easier to use is the really big lever. I believe that this endeavor will consume our attention for a good part of the next century.

In the last decade, anyone who has uttered the phrase "user friendly" in my presence has run the risk of physical assault. The phrase has been shamelessly invoked to suggest that a program is easy and natural to use when this is rarely true. Typically, "user friendly" refers to a program with a WIMP interface, meaning it relies on windows, icons, menus, and pointing along with an assortment of pretty colors and fonts that can be varied to suit users' tastes. This kind of overstatement is tantamount to dressing a chimpanzee in a green hospital gown and earnestly parading it as a surgeon. Let's try to penetrate the hype by painting a picture of where we really are with respect to user friendliness and where the true potential for ease of use lies.

Imagine requiring people to digest an 850-page manual to operate a pencil. We laugh at the thought but accept it readily in the case of a word-processing program.

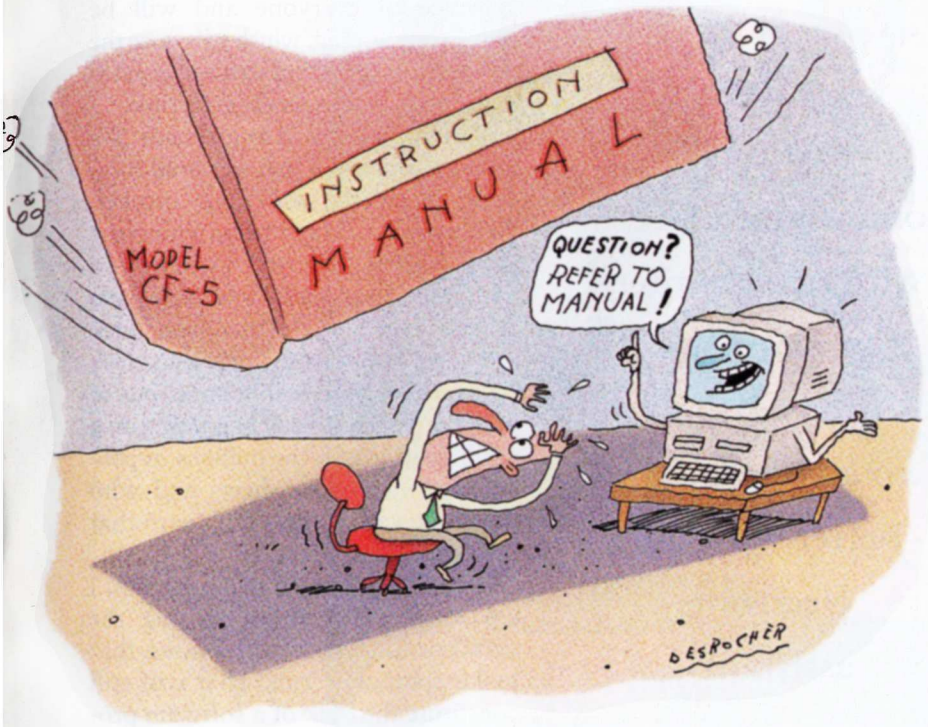
It is sometime in the late 1980s. A friend approaches you, excited by his ability to use spreadsheets. You ask him to explain how they work. He shows you a large grid. "If you put a bunch of numbers in one column," he says, "and then below them put the simple command that adds them up, you will see their total in the bottom cell. If you then change one of the numbers, the total will change automatically." The friend rushes on, barely able to control his exuberance: "And if you want to make the first number 10 percent larger, you just put in the cell next to it the simple command that multiplies it by 1.1." His expression becomes lustful: "Do you want to increase all the numbers by 10 percent? Just drag your mouse down like this, and they will all obey."

He takes in a deep breath, ready to explode once more, when you stop him cold. "Thank you. Now go away," you say. "You have taught me enough to do all my accounting chores." This is how millions of people today use their spreadsheet programs like Microsoft Excel and Lotus 1-2-3. They hardly know more than a tenth of the commands yet they get ample productivity gains.

You are happy with your newly acquired knowledge until one day you discover that you need to do something a bit more ambitious, like repeat over an entire page all the laborious operations you have set up but with a new set of ini-

tial numbers. Perplexed, you go back to your friend, who smiles knowingly and tells you that you must now learn about macros. His explanations are no longer as simple as before, and you just can't get the spreadsheet to do what you want. This is where most of the millions who use spreadsheets give up. But instead you fight on, eventually mastering the mysteries of the macro. It's really a computer program written in an arcane programming language that replaces you in commanding the spreadsheet program to do things you would have done manually.

You sail along for the next six months until you develop the need to do an even more ambitious task that involves designing a human-machine interface that will make your program more useful. You go back to your friend, who tells you that you have become too good for the limited capabilities of this spreadsheet application, and that you must now learn how to use a real programming language like C++. Unaware of what lies behind these three innocent symbols but unwilling to give up, you press on. This costs you your job, because you must now devote full time to a colossal new learning endeavor. Yet you are so enamored with programming that you don't mind. In fact, you like the idea. Two years later, having harnessed C++ and a few more programming languages and operating systems, you begin a career as a successful independent software vendor and eventually become wealthy.



This happy ending cannot hide the barriers that you have had to overcome along the way. You decide to graph the effort you expended versus the ability you gained. The result is a line starting at the left and moving along to the right. There is a long slowly rising portion and then a huge hill where you had to learn a lot of new stuff in order to move further right. Then there are more slowly rising lines and more huge hills, like a mountain chain where each new mountain gets higher. You wish that someone would invent an approach with a gentler slope, one where you get ever-greater returns as you increase your learning effort, without the impossible cliffs that you had to climb. I predict that such "gentle-slope systems," as I like to call them, will appear and will mark an important turning point of the Information Age.

The gentle-slope systems will have a few key properties. First and foremost, they will give incrementally more useful results for incrementally greater effort. They will be able to automate any activity you do that is repetitive. They will be graceful, in the sense that incomplete actions or errors on your part will result in reasonable degradations of performance rather than catastrophes. Finally, they will be easy to understand—no more complicated than reading a cookbook recipe.

CONCEPTUALLY CHALLENGED

One reason it is difficult for nonprogrammers to tell computers what to do is that the software systems that surround us are preoccupied with the structure rather than the meaning of information. We can program them to do anything we want, but they are unaware of the meaning of even the simplest things we are trying to do. Let me illustrate.

It takes me 17 seconds to say to a programmer, "Please write me a program that I can use to enter onto my computer the checks I write, along with the categories of each expenditure—food, recreation, and so forth. And do this so that I can ask for a report of the checks that I have written to date, listed chronologically or by category."

I have given this assignment several times to different people. Master programmers invariably decline to play and tell me to go buy this program because it's commercially available. Good programmers will say they can meet the request in a couple of hours—and end up taking a day or two to develop a shaky prototype. Inexperienced programmers will say cockily that they can write the program in a few minutes as a spreadsheet macro—and are generally unable to deliver anything at all. The company Intuit, which developed the very successful Quicken program that does this job and more, took two years and many millions of dollars to develop, test, document, and bring to market.

Why can I "program" a human being to understand the above instruction in 17 seconds, while it takes a few thousand to a few million times longer to program a computer to understand the same thing? The answer surely lies in the fact that humans share concepts like check, category, report, and

chronological, while computers do not. The machine is so ignorant of these concepts that programmers must spend virtually all of their programming time teaching the computer what they mean. If, however, I had a computer that already understood some of these "concepts," then I might be able to program it to do my job in a very short time. This is an important way in which computers could increase our productivity in the twenty-first century: by being made to better understand more human concepts in better ways.

For computers to be truly easier to use, technologists will have to shift their focus away from the twentieth-century preoccupation with the structures of information tools like databases, spreadsheets, editors, browsers, and languages. In their early stage, computers became ubiquitous because this focus allowed these common tools to be used equally in thousands of applications, from accounting to engineering to art. Yet that same generality is what makes them ignorant of the special uses they must ultimately serve and ultimately less useful than they should be—much like a dilettante jack-of-all-trades.

What we need now, to boost utility further, is a new breed of software systems like a spreadsheet that an accountant can easily program and that already "understands" higher-level repetitive tasks like setting up charts of accounts, doing a cash reconciliation, and pulling trial balances.

Freed from the tyranny of generality, these specialized programming "environments" will rise toward offering a lot more of the basic information and operations of their specialty. The time has come for computer technologists to abandon the "generalist" orientation that served people well for the first four decades of the computer era and shift their focus from the structure to the meaning of information.

We invented writing to communicate better with one another. Tomorrow we'll need a means to communicate better with our electronic assistants.

EVERYONE A PROGRAMMER

The biggest promise of the Information Age is the great and still unrealized potential of tailoring information technology to individual human needs. Today's applications programs are like ready-made clothes—one size fits all. So most are ill-fitting, and we have to contort ourselves to improve the fit. Another potential outcome of this practice for business is that if every company used the same set of canned programs, they would follow more or less the same procedures, and no company would stand out against the competition. Shrink-wrapped, ready-made software is good enough for the state of information technology at the end of the twentieth century. But it won't be as good in tomorrow's information marketplace.

Great gains will be achieved when individuals and businesses can bend and fashion information tools to do exactly what they want them to do, rather than bending themselves to what the tools can do. This quest for customizable information tools with specialized knowledge will be no different than the current trend toward customized manufacturing. It could well be that by the close of the twenty-first century, a new form of truly accessible programming will be the province of everyone and will be viewed like writing, which was once the province of the ancient scribes but eventually became universally accessible.

This isn't as absurd as it sounds. We invented writing so that we could communicate better with one another. Tomorrow we'll need to communicate better with our electronic assistants, so we'll extend our "club" to include them as well. Everyone will then be a "programmer," not just the privileged few. And none of them will be conscious of it. In fact, this is already happening on a small scale among the millions of people who use spreadsheets and who would be very surprised to learn that they are programmers.

When I say people will program, I am not talking about writing the detailed code and instructions that make computers run. That will still constitute the bulk of a software program and will indeed be created by professional programmers, who will fashion the many larger building blocks that we will use. Each individual's "programming" will account for a very small fraction of the software code, maybe 1 percent. But it will be the crucial factor that gives the program its specificity. It will be like building a model railroad; you don't make all the track or engines or cars, but you do arrange the pieces to create your own custom railway patterns.

We can increase the usefulness of our machines in the emerging information marketplace by correcting current human-machine faults, by developing automatization tools, and by creating a new breed of gentle-slope software systems that understand specialized areas of human activity—and that can be easily customized by ordinary people to meet their needs. Pursuing these directions should get us going on our quest, which I expect will last well into the twenty-first century, to harness the new technologies of information for the fulfillment of ancient human purposes. ■

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BY DONALD A. NORMAN

Melding Mind and Machine



The computer doesn't work like the human brain. But that's OK. Each has different strengths. All we need to do is figure out a way to make them work together.

A common prediction among technologists—and a common fear among the general population—is that computers and robots will come to mimic and even surpass people. But there is no way this is likely to happen in the foreseeable future. The reason is that computers and people work according to very different principles. One obeys strict logic and yields precise, repeatable results. The other follows a complex, history-dependent mode of operation and yields approximate, variable results. One has been carefully designed according to well-determined goals. The other has been cobbled together over eons of evolutionary trial and error.

ILLUSTRATION BY GARY COLBY

It's good that computers don't work like the brain. The reason I like my electronic calculator is because it is accurate. If it were like my brain, I wouldn't always get the right answer. Together we are a more powerful team than either of us is alone: I think about the problems and the method of attack; it does the dull, dreary details of arithmetic or, in more advanced machines, of algebraic manipulations and integration.

The computer's strength results from a large number of simple, high-speed devices following binary logic and working reliably and consistently. Errors in the operation of any of the underlying components are not tolerated and are avoided either by careful design to minimize failure rates or through error-correcting coding in critical areas.

The power of biological computation results from a large number of slow, complex devices—neurons—working in parallel through intricate electrical-chemical interactions. Errors are frequent—whole cells may die—but reliability is maintained through massive redundancy.

Unnatural Acts

While the biological computation process itself is inherently error-tolerant, our actions—unlike the output of computers—are fraught with imprecision and inaccuracy. In response, humans have developed systems that can handle ambiguity. In fact, in many cases they were forced to do so in order to survive as a species.

Human language, for instance, provided people with a powerful means of communicating and cooperating that enabled them to adapt to complex, changing environmental forces. As language evolved and conformed to human needs, it developed into a robust, redundant, and relatively noise-insensitive means of social communication. It is flexible, ambiguous, and heavily dependent on shared understanding, a shared knowledge base, and shared cultural experiences. As a result, errors in speech are seldom important. Utterances can be interrupted, restarted, even contradicted, without causing confusion.



At times I feel a merger with my word processor. I think the words and they appear on the screen in front of me.

Human language is so natural to learn that people master their native tongue without any formal instruction—they must suffer severe brain impairment to be incapable of learning such language. Human language is also easy to use since any errors in speech are corrected so effortlessly that often neither party is aware of the error or the correction.

Conversely, a large proportion of the population would find programming languages difficult to learn and use. Even the most skilled programmers make errors, and error correction occupies a significant amount of a programming team's time and effort.

Human error often goes unnoticed, but it can be a problem in a technology-centered society where people are asked to perform "unnatural" tasks that would never be required in the natural world—such as to do detailed arithmetic calculations, or to remember details of some lengthy sequence or statement, or to perform precisely repeated actions. All are a result of the artificial nature of manufactured and invented artifacts, and the resulting errors are the consequence of an inelegant fit between human cognition and arbitrary demands.

Best of Both Worlds

Alas, today's attempts to minimize errors are misguided. One strategy has been to make humans more like computers. According to today's machine-centered point of view, humans would rate all the negative characteristics (vague, disorganized, distractible, emotional, illogical), while computers would earn all the positive ones (precise, orderly, undistractible, unemotional, logical). A complementary approach, however, would assign humans all the positive traits (creative, compliant, attentive to change, resourceful) and computers all the negative ones (dumb, rigid, insensitive to change, unimaginative).

For example, let's compare the children's game tic-tac-toe with the Game of 15. Tic-tac-toe is represented perceptually: the goal is to form a straight line of three of your pieces before your opponent does. The Game of 15 is numeric, or symbolic: it is played by two opponents alternately selecting digits until one person has succeeded in accumulating three digits whose sum is 15.

The Game of 15 is logically equivalent to tic-tac-toe, but people find the Game of 15 difficult and tic-tac-toe simple. The difference lies in the form of representation. People play tic-tac-toe by glancing at the board and observing which pieces form a straight line and which do not. Humans excel at such pattern recognition, especially context-

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dependent recognition. Thus they are very good at interpreting information, finding explanations of phenomena rapidly and efficiently, and integrating meaning and context into the task. They can even go beyond the information available, relying heavily on a large body of prior experience.

But people perform poorly when processing numeric information such as that required by the Game of 15, since human symbolic processes are slow, serial, limited in power and by the size of working memory. Thus people are poor at maintaining high accuracy, at integrating large quantities of symbolic information, and at detecting patterns in symbolically displayed information.

Computers, in contrast, lack any kind of perceptual system, so it is difficult to program a computer to play tic-tac-toe by doing a perceptual analysis of lines and other geometric patterns among the pieces. Of course, tic-tac-toe doesn't present much of a challenge for computers. But this is because they are usually programmed so that the representation used for tic-tac-toe is very similar to that used for the Game of 15, relying on a brute-force search through the tree of possible moves.



A Meeting of Minds

It should be possible to ensure cooperative interaction between people and computers that relies on the strengths of each. Are there examples of systems that take the fullest advantage of the complementarity of people and machines? Yes. Consider white-water canoeing. The canoe is really a merger of the skills of the person and the capabilities of the craft. The canoe-person system negotiates the rapid: to the person, the canoe is part of the body, an integral whole with the activity.

At times I feel the same merger with my word processor. I think the words and they appear on the screen in front of me. Ideally, the word processor complements my thinking, simplifying the output process without getting in the way. Later, it helps me reflect on the writing, make "what-if" changes, and even get the spelling and punctuation right. "What-you-see-is-what-you-get" operations mean that I can manipulate the text so that its physical format looks right, just as the text reads right. Here, the computer handles what it does best, while letting me concentrate on what I do best.

Unfortunately, this state is not long maintained, for modern word processors are really still technology-centered in design, continually interrupting me with so-called "dialog" boxes, presenting more menu choices than I care to think about, and in general getting in the way. Still, there are moments when the technology fades and it is just me, my creativity, and the resulting writing.

One way to exploit these differences is to use the power of computers to translate data sets into perceptual representations that people are more comfortable with. The development of modern computers and their associated fast, real-time, interactive display systems makes it possible to translate otherwise symbolic information into a format that fits human cognition. Usually this means presenting perceptual information rather than symbolic or numeric. But it also means eliminating or minimizing the need for people to provide precise numerical information, so they are free to do higher-level evaluation, to state intentions, to make midcourse corrections, and to reformulate the problem.

Complementarity between people and computers also exists in some systems for scientific visualization. Scientists use the computer as the medium for displaying data from a variety of viewpoints and the human perceptual system as the medium for noticing significant patterns.

We should develop more systems that rely on the complementary properties of people and machines. The principles are well known, if seldom followed. We need a different breed of designer, one less immersed in technology and more focused on the people the technology is intended to serve.

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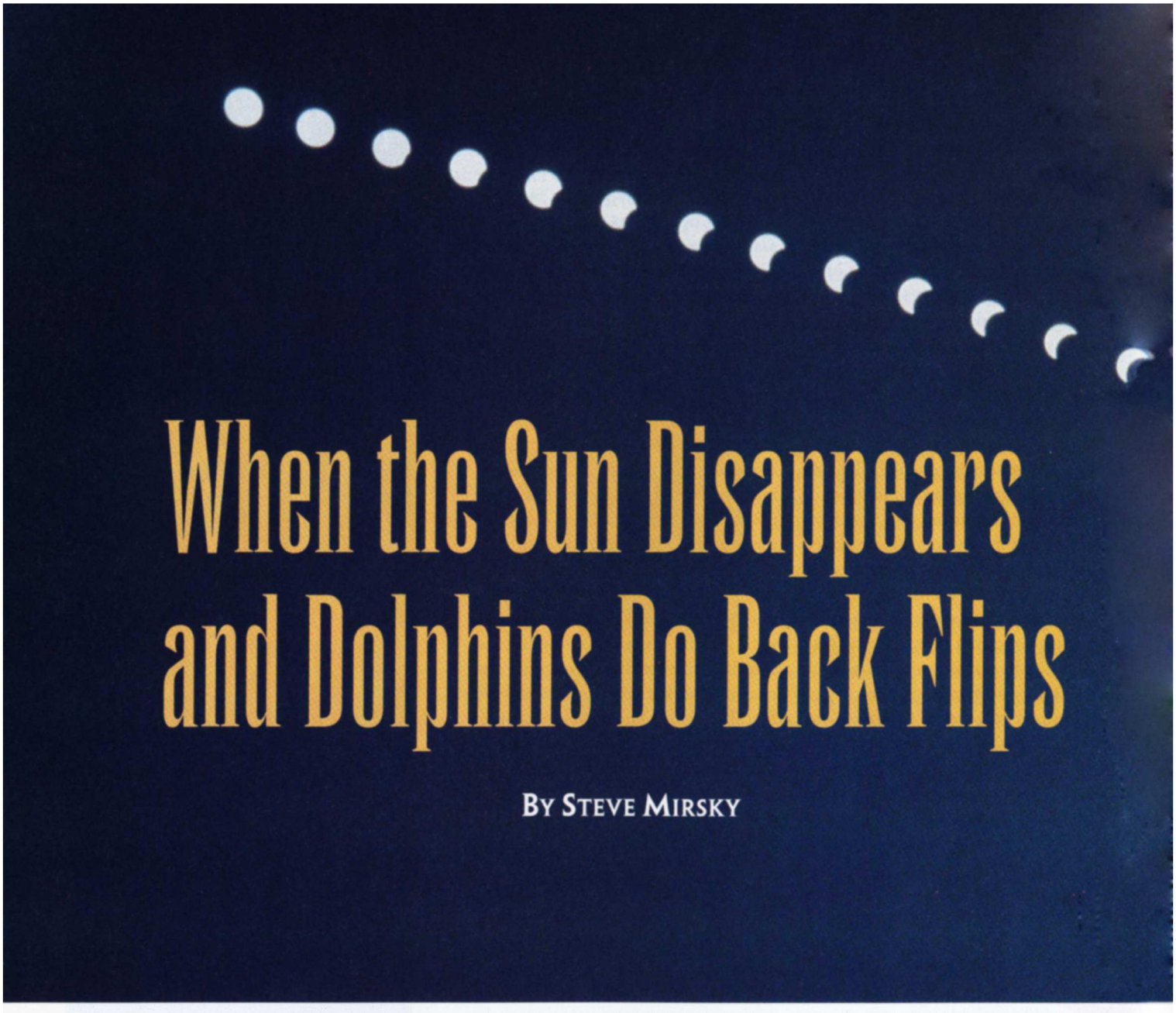
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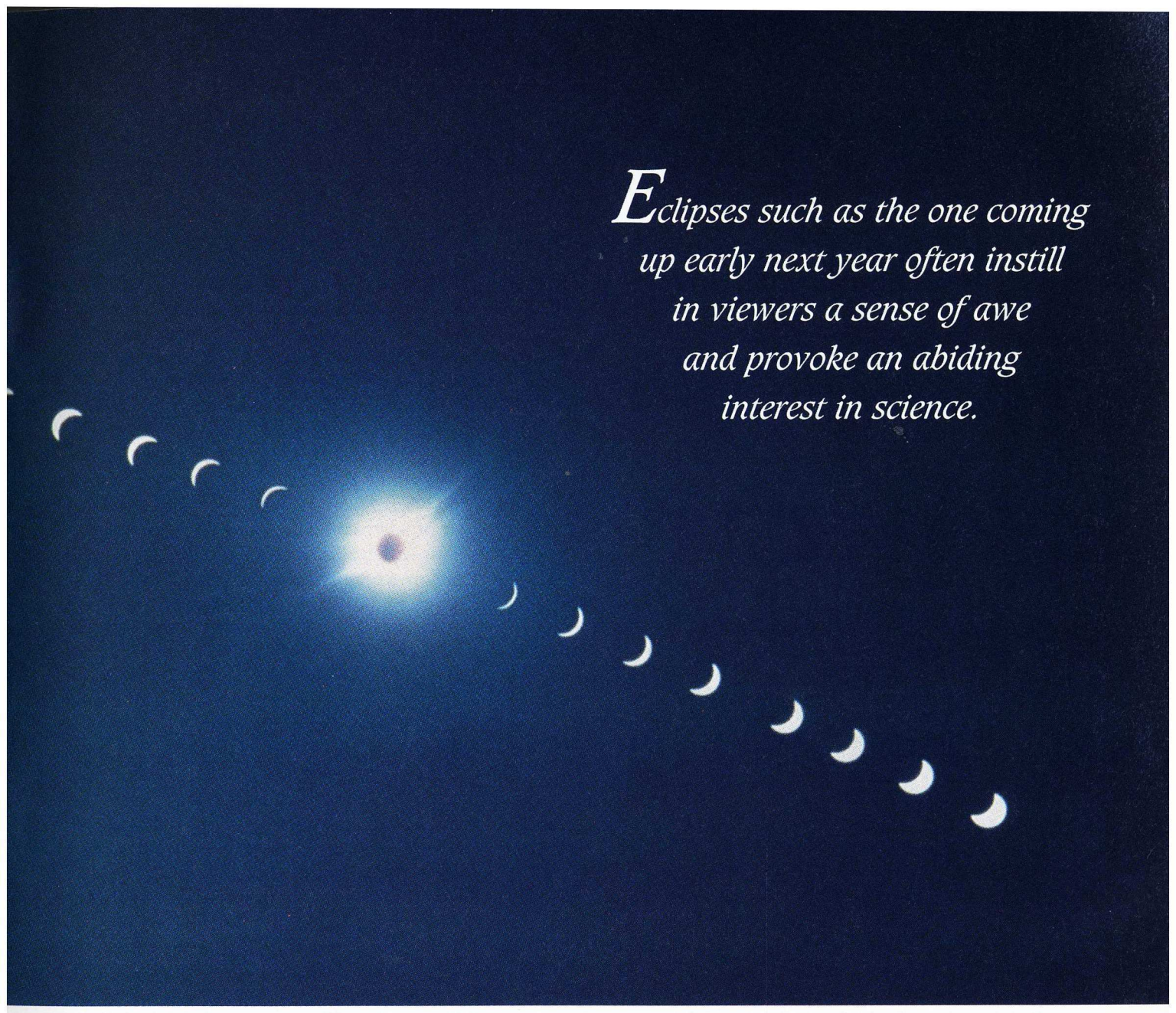


When the Sun Disappears and Dolphins Do Back Flips

By Steve Mirsky

SINCE death and taxes are the only sure things in this life, it falls to the individual to come up with a compelling To Do list to fill the brief measure of time between cradle and grave. The list may include such obvious entries as: find a lifelong companion, get a good career, and change the oil every 3,000 miles. A less obvious entry, but one that belongs very high up, should be: witness a total solar eclipse, such as the one that will sweep over the Caribbean for a respectable four minutes on February 26, 1998. In 1991, I stood under the shadow of the moon for almost seven minutes, aboard a ship in Mexico's Sea of Cortez. You want this kind of experience. Trust me. Although eclipses helped confirm Einstein's theory of relativity, scientists no longer rely on them for much new knowledge. Satellites can get most solar data better and faster than can eclipse expeditions, which scientists had to organize to obtain such information during the early

PHOTO: MICHAEL REARDON



Eclipses such as the one coming up early next year often instill in viewers a sense of awe and provoke an abiding interest in science.

part of this century. What eclipses still can do, however, is fill us with the kind of wonder that sparks a scientific interest in the first place. Besides, it's a hell of a show. ❁ On July 8, 1991, having made arrangements a year or so in advance, about 1,300 professional and amateur astronomers boarded the cruise ship *Viking Serenade* in Los Angeles. We set sail for the sliver of sea between the Baja Peninsula and the rest of Mexico, one of the prime locations for the solar eclipse that would be visible, weather permitting, three days later in a narrow band stretching from Hawaii to Brazil. We did this despite the comments of one Jesús Arais, who told the *New York Times* he planned to watch the eclipse on television from the comfort of his home in San José Viego, Mexico. "It's a little crazy for the gringos to come so far to sweat," Arais said. "They have much better televisions than we do." ❁ Nevertheless, we wanted to see for ourselves what people have always fussed



People used to behave during eclipses as if they were being abandoned by their gods. But the crush of amateur astronomers would cause the only obvious havoc aboard a cruise I took to observe a total solar eclipse in 1991.

about whenever the moon gets between the earth and the sun. "Most ancient peoples were alarmed by the occurrence of an eclipse," E. C. Krupp, the director of Los Angeles's Griffith Observatory, told us on the *Serenade*. "They were anxious about what the eclipse might mean."

"Eclipse" is a Greek word, its root meaning omission or abandonment. People certainly used to behave during eclipses as if they were being abandoned by their gods. Krupp, who researched the subject for his book *Echoes of the Ancient Skies*, described the reaction—as recorded by sixteenth-century Aztecs—to an eclipse visible from Mexico. There was "a tumult and disorder, all were disquieted, unnerved, frightened. There was a weeping. The common folk raised a cry lifting their voices, making a great din, calling out, shrieking," while in the temples chants were sung. Furthermore, "people with light complexion were slain. All offered their blood." A warning was given that "if the eclipse of the sun is complete, it will be dark forever. The demons of darkness will come down, they will eat men."

I would discover that eclipse watching still induces a frisson of fear. I blame some evolutionarily grounded hard-wiring that bypassed my scientifically informed brain and told my body that something highly unusual and maybe even dangerous was going on. Eyewitness accounts of animal behavior during eclipses describe other creatures, too, as seeming upset. These astronomical events have probably been creating havoc for millions of years.

The crush of amateur astronomers would cause the only obvious havoc aboard the *Serenade*. One person wore a T-shirt showing the locations and total amount of time he had spent under the eclipsed sun. Another looked a great deal like the TV character Gomez Addams, probably because he was actually actor John Astin, a passionate amateur astronomer. (I first spotted him during a lifeboat drill. The possibility of sharing such a craft with the sire of the "Addams Family" affirmed my belief that this could be an interesting trip.) Our little voyage would be less emotionally taxing than the experience of our ancestors. We foresaw little chance of ritualistic mass murder. And where scientists seeking to confirm the theory of relativity had to endure grueling expeditions—such as delineating a safe route among enemy countries during World War I, or trekking 100 miles to an Australian site using camels to carry dismantled telescopes—on our trip we had only to come to grips with a lifestyle that could be a bit, well, loopy.

For one thing, preparation for observing the eclipse—on a ship designed for indulging vacation fantasies toward the end of the twentieth century—seemed to take a back seat to seeing how much we could eat. Cruises, I learned, commonly engage in this form of subtle torture. Buffets started at dawn and continued past midnight, in addition to regular meals and room service. (Any passenger on an eclipse cruise should bring two safety items: a solar filter for viewing the partial eclipse, and really big pants.)

Our trip's organizers had arranged for numerous scientific seminars. Still, an unusual ambience also tinged these, for the rooms in which the talks took place ordinarily hosted lounge singers and bingo games. The names of the nightclubs, in keeping with their true identities, give an idea of the cognitive dissonance and kinds of upholstery to which passengers were subjected. One could listen to the presentation "The Corona of the Sun and X-Ray Astronomy" in the Hello Dolly Lounge or "Very Long Baseline Interferometry" in the Aïda Dining Room.

The scientific talks did not waste much time describing the simple physics of eclipses, which are downright banal. Three bodies moving relative to one another more or less in a plane occasionally line up. Big deal.

We did learn, however, that some critical relationships make a complete eclipse striking to the mind as well as the eye. Consider the relative sizes and distances of the entities involved. If the earth were 2 inches wide, the moon would be a shade over 0.5 inch across and 5 feet away. Meanwhile, the sun would bulk in with an 18-foot diameter and would stand two-fifths of a mile distant. Both sun and moon happen to occupy about one-half of one degree of sky, the moon being just about 400 times closer to us than the sun, but the

STEVE MIRSKY, a freelance writer, wrote about budding TV weather forecasters in the November/December 1996 issue of Technology Review. *An earlier version of this article appeared in* Einstein *magazine.*

PHOTO: CYNTHIA JONES

Eclipses and Einstein

SCIENTISTS hoping to confirm or disprove Albert Einstein's theory of relativity first counted on eclipses to provide their experimental data. The theory says that light energy, being equivalent to matter, will be attracted by masses. Therefore, the sun should attract passing light. Predicting that any massive objects such as the sun would deflect passing light, in 1911 Einstein thought of testing the idea by taking advantage of solar eclipses to measure the deflection of starlight.

The idea was to compare a section of the sky photographed during an eclipse with ordinary nighttime images of the region. At night, the light from distant stars reaches the earth directly. During an eclipse, our sun is between them and us. According to Einstein's hypothesis, photos of stars near the eclipsed sun would show them to have moved just a tad, having been pulled toward the solar mass, when compared with their positions in photos taken at night. Astronomers and physicists packed up their cameras, took their quinine pills, and set off for the ends of the earth.

Bad weather and World War I hindered the initial expeditions. Then two sets of British scientists photographed starlight in Brazil and South Africa during an eclipse occurring May 29, 1919. While the results seemed to confirm the General Theory of Relativity, the calculations—made by measuring the tiny changes in position in eclipse and night photos—from the two places "conflicted with each other by more than what was supposed to be the probable error," said Donald Osterbrook, professor of astronomy and astrophysics at the University of California at Santa Cruz, during the 1991 *Viking Serenade* eclipse voyage I took.

To settle the mystery, in 1922 William W. Campbell, director of the Lick Observatory and one of the era's preeminent astronomers, traveled to Australia for the next eclipse. Because the event was fairly long—five minutes—"faint stars could be recorded. Therefore you could see more stars closer" to the sun's edge, explained Osterbrook, and observers had "a better chance to measure the effect." On April 12, 1923, Campbell announced that the photos did indeed show that the placement of the images of stars nearest the sun in the skyfield appeared to have changed a tiny bit compared with photos of the same field at night. Compared with Einstein's prediction that starlight near the rim of the sun would be deflected 1.75 seconds of arc, the data were "as close as the most ardent proponent of the relativity theory could hope for," said Campbell, according to Ronald L. Clark in his book *Einstein: The Life and Times*.

Strangely enough, Campbell had not wished to find himself living in a relativistic universe. "I hoped it would not be true," he later said, perhaps because the theory went against what seemed like common sense. Einstein, of course, had already accepted relativity as the universe's norm. In fact, when experimental verification of relativity was announced, he is said to have commented, "But I knew that the theory is correct." Ilse Rosenthal-Schneider, the Einstein student who related this story, then asked him what would have happened had the eclipses not confirmed relativity. Einstein replied, "Then I would have been sorry for the dear Lord—the theory is correct." ❁ *Steve Mirsky*

sun having around 400 times the diameter of the moon, a coincidence of cosmic significance to eclipse watchers.

That's not all that counts, either. Since we are in an elliptical orbit around the sun, and the moon is in an elliptical orbit around us, the bodies are not always the same distance from us, which means their apparent sizes vary slightly at different times. If the moon is far enough from us while the sun is at a close point in our orbit, the moon can be too small to block the entire sun.

Fortunately, our situation was the exact opposite. The moon would be almost as close as it gets (just a few hours past perigee, its closest point to us). The sun, on the other hand, would be almost as far away as it gets (with the earth being only five days past aphelion, the point in our elliptical orbit when we are at our greatest distance from the sun). Thus we would not only be certain to experience totality, but the relatively large apparent size of the moon would block the relatively small apparent size of the sun for an exceptionally long period—about seven minutes, depending on where one stood on the earth. Not until June 13, 2132, will the heavens grant a longer total solar eclipse.

We were primed. Then, the day before showtime, the equivalent of a sprained ankle before a marathon threatened us: clouds. An eclipse on an overcast day is like watching *Star Wars* when the curtain is down. Swaths of blue sky that afternoon eased the tension.

Still, the possibility prompted the passengers to talk softly—do people equate loudness with jinxing?—about what complications might ensue. "The weather has ever been the despotic rule over the fates of eclipse expeditions," wrote Isable Lewis in the U.S. Naval Observatory's *1924 Handbook of Solar Eclipses*. Indeed, at dawn on the big day our direction—now past the tip of the Baja, we were heading northeasterly—found us traveling toward a block of cirrus clouds. But being at sea gave us a trump card: we could travel elsewhere. By contrast, clouds would shut out many people who had traveled to a stationary position in Hawaii.

In fact, part of our saving grace turned out to be some-



For one hour and 24 minutes the moon smoothly sealed off the light, like a cover sliding across a camera lens. We watched the partial eclipse through our solar filters or projected images of the crescent sun onto the deck—and the backs of T-shirts—through inverted binoculars.

one who came from Hawaii, specifically its state university—James C. Sadler, a professor of meteorology. Consulting satellite photographs of the area that were faxed onboard, he convinced the scientific overseers of the trip that "the only thing to do was turn back toward the northwest," recalls Joseph Chamberlain, then president and director of Chicago's Adler Planetarium (now president emeritus). Still, "the ship was only going 6 knots, and we knew the clouds were catching up with us. We increased the ship's speed another 6 knots" and the clouds fell back. The nearly 2,000 passengers and crew took up positions on the uppermost decks amid the brilliant colors of sun-glorified sky and sea.

Krupp of the Griffith Observatory offered an observation about what we would next experience. "A total solar eclipse is one of the grandest, if not the grandest, spectacles that nature stages. For that reason it is very hard to describe to someone who has never seen" such a show.

At 33 seconds past 11:30 a.m. Mountain Daylight Time, the moon gently nudged the edge of the sun, then slipped over it. For the next hour and 24 minutes the lunar disk smoothly sealed off the light, like a cover sliding across a camera lens. We watched the partial eclipse through our solar filters, made of thick, dark welder's glass, or we projected images of the increasingly crescent sun onto the deck through inverted binoculars. During most of the partial eclipse, the ever-diminishing sun still pumped out enough light so that anyone unaware of the event would have still thought all was normal—although crescent-shaped shadows had started to appear.

When only a slender shaving of sun was left, however, the sky seemed to suddenly darken. About three minutes remained before totality. With the warming sunlight all but gone, the air quickly cooled and the wind picked up. We stood waiting on the top deck, drifting quietly and bobbing gently while the shadow of the moon swept toward us at 1,300 miles per hour. Finally, at 12:54:12 p.m., the sun blinked out.

That tingle of earlier-mentioned fear ran down my spine. With no light whatsoever shining on it, the side of the moon facing us completely disappeared. Instead, a featureless black disk hung in the sky, like a hole in the otherwise star-studded heavens. With the sun completely concealed, we could now abandon filters and look at the eclipse with impunity.

Surrounding the disk was the sun's corona, ordinarily invisible because of the sun's intense luminescence. Photographs of coronas as flashy splotches do not capture the actual scene, since an accurate portrayal would require a range of exposure settings. The corona we saw consisted of innumerable gray and white gossamer strands reaching more than three solar diameters across the sky. Red tongues of flame protruded from the top and bottom of the black hole.

So far, the only relevant physics had been Newton's mechanics, describing the movement of the bodies. Now Maxwell's electromagnetics provided the show, with the corona, made of gases whose electrons had been torn off by millions of degrees of heat, describing the shape of the sun's magnetic field. Eugene Parker—winner of the U.S. Medal of Science for his studies of the sun, and a professor in physics, astronomy, and astrophysics at the University of Chicago—explained later that the red prominences, which are also related to particular regions of magnetism, were clouds of relatively cool hydrogen—a mere 8,000 to 10,000 degrees Celsius—whose glow comes from electrons dropping to lower energy levels. These were "probably 50,000 miles high and a few hundred thousand miles wide," he said.

Planets also became visible. West of the moon shone Mercury, Jupiter, Mars, and Venus in an almost perfect row.

For one second shy of 7 minutes, all of us on board gazed upward, trying to freeze time and store the images, as well as the totality of our experience. Then, at 1:01:11 p.m., a solitary point of light appeared along the moon's rim—and the sun turned back on. The speck was enough to cause the so-called Diamond Ring effect: a sliver of light circling the moon. That was enough to make the corona disappear. The horizon—which like our sunsets had burned deep red partly as a result of light-reflecting dust from volcanic eruptions earlier in 1991—began lightening. Normalcy crept back.

Several minutes later, dolphins—which we had seen often

CONTINUED ON PAGE 68

PHOTO: CYNTHIA JONES

Climb...



TO THE ROOF OF AFRICA AT 19,340 FEET
KILIMANJARO CLIMB—Sept 18-25, 1997
TANZANIA SAFARI—Sept 25-Oct 4, 1997

This September join us for an exciting 7 day expedition to reach the summit of Mount Kilimanjaro. Following the climb, join MIT Professor Emeritus Patrick Leehey as he leads our group on safari in Tanzania through the Ngorongoro Crater—Africa's "Garden of Eden"—Lake Manyara National Park and Tarangire National Park. Professor Leehey, of MIT's Harold Edgerton Center, will take his photographic expertise and knowledge of the area on the road as we discover and photograph the beauty of Tanzania.
(Safari and climb programs may be purchased separately.)

Explore...

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Learn...

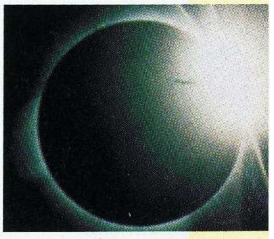
ABOUT THE HISTORIC TRADITION & MODERN TECHNOLOGY OF SCOTLAND—Sept 15-25, 1997

MIT Professor Emeritus Ernst Frankel will lead the group as we learn about the work of architect Charles Rennie Mackintosh and visit Glasgow's and Edinburgh's fine museums and modern centers of industry. We will also explore the scenic Grampian Highlands and visit Stirling Castle, Scone Palace and the lenfiddich Distillery. Join us on a relaxing, informative tour of bonnie Scotland.



Witness...

A TOTAL SOLAR ECLIPSE DURING A CARIBBEAN CRUISE—Feb 23-Mar 5, 1998



On February 26th, as we reach the coordinates 11° 56' north latitude, 70°19' west longitude, stars and planets will become visible as we observe one of Nature's most awesome spectacles, a Total Solar Eclipse. Joining us on board will be astronomers, meteorologists and expert photographers who will prepare us for the event. We will travel on board the Stella Solaris. Our ports of corts include Curaçao, Aruba, Jamaica and Cozumel.

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Defusing AIRLI

A variety of high-tech bomb detectors are under study, but certification, cost, and privacy dilemmas could keep them from your local airport.

By Mark Fischetti

THOUGH it takes a sick mind, it isn't hard to bomb a U.S. airliner. The security equipment in place at the nation's airports was mandated in the 1970s, when the chief concern was hijackings, not terrorist bombings. So while the metal detectors we all step through can uncover guns, knives, and other metal weapons, they can't find hidden explosives. Neither can the x-ray machines that scan carry-on bags, as well as checked luggage for international flights. Checked luggage and mail for domestic flights are not examined at all.

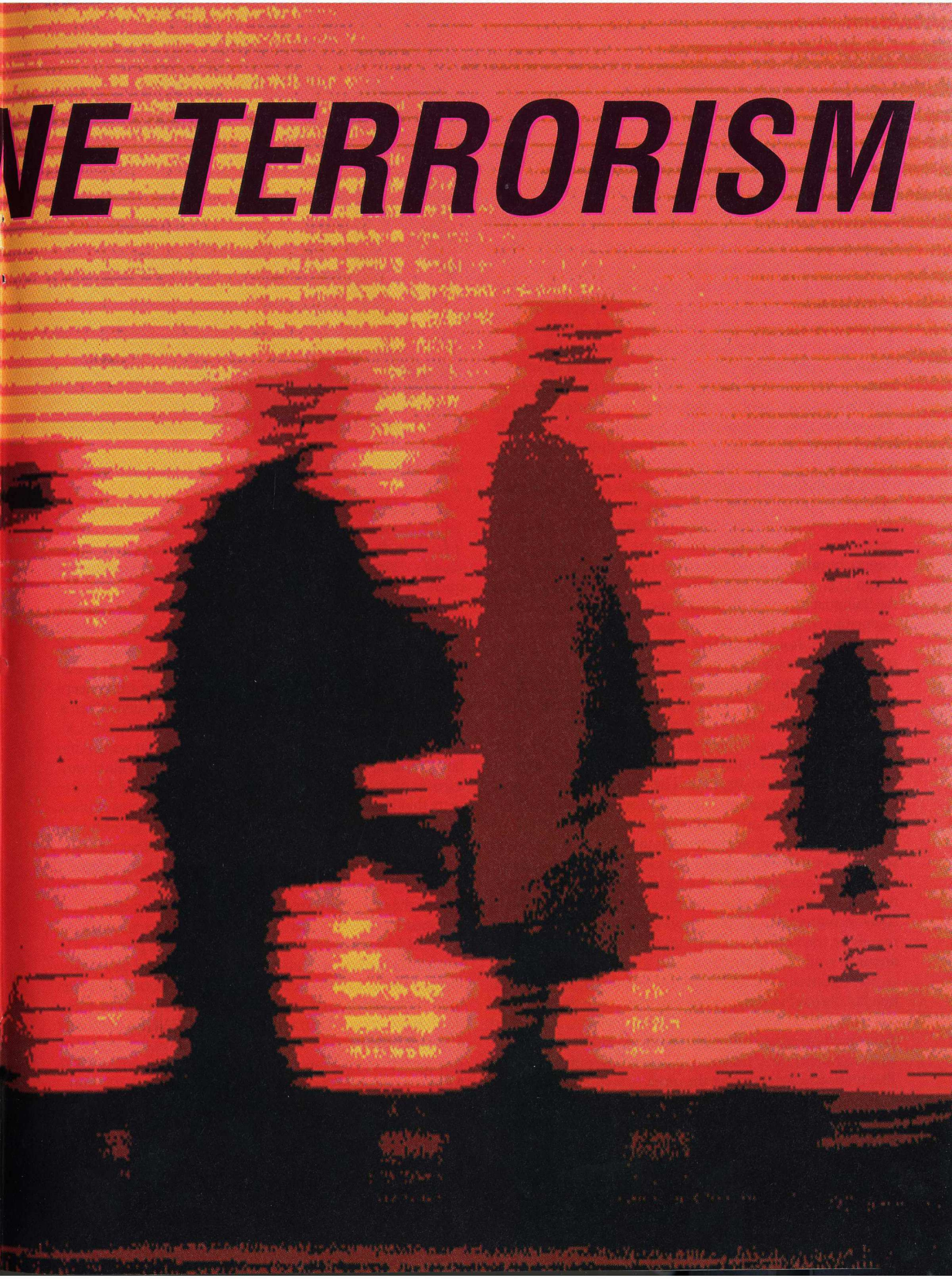
But recent bombings in Oklahoma City and Atlanta's Olympic Park, the FBI's discovery of plots to blow up U.S. airliners, and speculation about the downing of TWA Flight 800 in July have produced strong calls for protection against demolition-minded terrorists. Politicians have been jolted into action. After years of little legislative attention, Congress on October 9 suddenly appropriated $160 million for the Federal Aviation Administration (FAA) to rush more than 500 bomb detection units of various types into airports for a year of testing.

Some observers say this action is long overdue. Others say it is too hasty. No fewer than 10 detection schemes are vying for position—from x-ray machines and magnetic resonance imagers to chemical-vapor sniffers. Although they have different pros and cons, no single machine is both fast enough and accurate enough to meet the FAA's certification criteria. All the proposed systems are expensive. They also raise serious social concerns. The National Research Council (NRC) recently concluded that ultimately "limitations on the technology will be imposed as a result of passenger intoler-



PHOTOGRAPH: TONY STONE IMAGES/MARTINE MOUCHY
DIGITAL COLORIZE: LORI NOLLET DAMON

NE TERRORISM



ance for invasion of privacy, delays, or discomfort."

Even if the technical and human issues are resolved, the biggest question remains: Who will pay to protect the skies, and is the price worth paying?

The drive to screen for bombs gained momentum after the 1988 downing of Pan Am Flight 103 over Lockerbie, Scotland, which killed all 259 people on board. R&D accelerated on technology that could detect less than a pound of explosives hidden on a person's body or in luggage. Legislation directed the FAA to find automated machines that could uncover explosives without human operators.

In 1993 the FAA set two key standards. To become certified, a machine would have to process 450 people or bags an hour, the approximate "throughput" of current carry-on bag scanners. It would also have to have a low false-alarm rate, reportedly 10 to 20 percent of all inspections. Meeting both numbers proved difficult, and the automation requirement was an obstacle that few manufacturers were able to overcome (most of the latest systems still need people to run them). But U.S. manufacturers didn't seem concerned; they were selling systems to Israel and Europe, where standards are less stringent. Besides, no further bombings had occurred, so U.S. airlines were not buying.

The heat increased in 1995 after Ramzi Ahmed Yousef, the suspected mastermind behind the 1993 World Trade Center bombing, was implicated in a plot to blow up a dozen U.S. airliners. His laptop computer, confiscated in the Philippines, stored flight schedules and detonation times. Accordingly, the NRC formed a committee on detection technologies. It issued its first report, pointing out relative strengths and weaknesses of various systems, in June 1996. The FAA responded by assembling a security task force on the morning of July 17; that evening, TWA Flight 800 blew up over Long Island Sound, killing all 230 people aboard.

Although the cause has yet to be determined, the July catastrophe set off a flurry of activity that is rapidly putting new technology into airports. The White House set up a Commission on Aviation Safety and Security under Vice-President Al Gore and gave it a mere 45 days to present a national technical strategy. In the frantic last days of its fall session, Congress banged out the October 9 Federal Aviation Reauthorization Act. The legislation earmarked $160 million for aviation security, tracking the Gore commission's recommendations that a variety of new detection techniques be tried out in real settings to identify the ones that are most ready for deployment.

Just like that, the FAA had money and a mandate. It quickly decided to purchase and deploy more than 50 special x-ray units, 400 chemical-sniffing machines, and other instruments to screen passengers and bags at 75 of the country's largest airports. Tests would be held over the next year. The first contracts were let the week before Thanksgiving. This infusion has rekindled widespread work—and debate.

MARK FISCHETTI, a freelance technology and business writer based in Great Barrington, Mass., has written for Smithsonian, Scientific American, *and many other magazines.*



SEE THE EVIL, HEAR THE EVIL, SMELL THE EVIL

Explosives can be "seen" with imaging equipment that peers through clothing or baggage, "smelled" with instruments that react to vapors or particles, or "heard" with machines that pick up radio-frequency echoes of the material.

Although the densities of explosives—and plastic weapons, for that matter—are too low to be detected by conventional "transmission" x-rays, where a single beam of energy passes through an object, other types of x-ray machines can do the job. American Science and Engineering (AS&E) in Billerica, Mass., and Nicolet Imaging Systems in San Diego make machines that analyze "backscatter" x-rays. Different materials reflect x-rays in different ways. This backscatter is captured by sensors in the walls of a hatchway surrounding a bag or a person. It is then analyzed by software that looks for signatures of lower-density items (a plastic knife, for example) and those of substances with low atomic numbers, such as nitrogen, which are characteristic of explosives. These objects are shown on the operator's screen. By isolating questionable items, this scheme can thwart the common terrorist tactic of concealing explosives amongst clutter.

AS&E's machines are installed at numerous prisons, U.S. Customs checkpoints, airports in Europe, and the White House. The 101ZZ, which requires an operator, can scan up to 600 bags an hour, exceeding the FAA throughput standard. But its false-alarm rate is above the FAA limit; it's difficult to distinguish a roll of plastic explosives from a rolled up magazine or a salami. The machine costs from $80,000 to $120,000; an automated version costs about $300,000.

The darling of the x-ray contenders for screening bags is the CTX-5000, made by InVision Technologies in Foster City, Calif. The computed-tomography machine, similar to the CT scanners used in hospitals, takes cross-sectional slices and combines them into a three-dimensional image.

PHOTOS: REUTERS/CORBIS BETTMANN





Terrorism *emerged as the cause of the Pan Am Lockerbie explosion (left). The investigation of wreckage from TWA Flight 800 (above), though inconclusive, has fueled the drive for better security.*

Although its false-alarm rate meets the FAA's criteria, the system is slow; two machines must operate in parallel to process 450 bags an hour—an expensive configuration at about $1 million a machine. Nevertheless, the FAA has granted certification for systems comprising at least two CTX-5000 machines. In late December the agency signed a $52.2 million contract with InVision to install more than 50 machines at major airports, including Chicago's O'Hare.

EG&G Astrophysics in Long Beach, Calif., makes a lower-cost variant that takes just two, orthogonal slices. While better than a standard transmission x-ray photo, the image is less refined than that of the CTX-5000.

Vivid Technologies in Woburn, Mass., uses x-rays of two different energies, each absorbed most strongly by materials of a different density. By comparing the relative attenuation of the two beams, the system can distinguish objects from background clutter, and also determine a mean atomic number for a given object delineated in the image. If, for example, the system spies a mysterious brick, it can give an average number for the entire object (which may consist of several different materials). It then compares this number to those of explosives. If there is a correlation, a guard opens the bag to see whether the brick is a chunk of explosive or a block of cheese. The difficulty is that the atomic numbers of the 12 or more common explosives, including TNT, nitroglycerin, and RDX and PETN plastics, are similar to those for common compounds, from foodstuffs to books, so again false alarms are high. Vivid's machines cost from $250,000 to $400,000.

Another unit, made by Millitech Corp. in South Deerfield, Mass., exploits the fact that all objects not at absolute zero emit electromagnetic energy. The scanner differentiates objects by analyzing their emission patterns in the extremely high frequency range (near 100 gigahertz). Interpreting the rather grainy images requires highly trained operators, however. The benefit is that passengers are not exposed to x-rays.

Explosives that aren't seen might be smelled with "trace detectors" that react to small quantities of tell-tale vapors or particles. In this approach, people or bags pass through a closed portal. Air is blown over them, and the vapors or particles are collected for chemical analysis. In some machines, passengers push open "saloon" doors, or walk through brushes, which pick up particles left on their clothing or hands. Alternatively, an operator can rub a wand along the person or bag to vacuum up vapors and particles. This technique is attractive for analyzing laptop computers, radios, and other electronics, which set off metal detectors but cannot be taken apart for inspection. Since x-ray machines can't distinguish objects amid the cluttered circuitry, electronic devices are among terrorists' favorite hiding places for explosives.

The most widely deployed trace detector is the wand-style EGIS system, made by Thermedics Detection in Woburn, Mass. The machines are used at 42 airports in 12 countries to scan bags and are also used at border crossings in Israel. At the end of November, the FAA placed a $1 million initial order for the machines—which sell for $150,000 to $200,000 apiece—under the October 9 appropriation.

With EGIS, an operator passes a vacuum wand the size of a compact umbrella over the bag. The wand is then inserted into an analysis unit, which uses gas chromatography to separate the elements in the sample and determine their concentrations. This enables the system to distinguish between nitrogen compounds in plastic explosives and those in foodstuffs. The unit displays a red light if explosives are found, and indicates whether it is TNT, nitroglycerine, or plastic. According to Thermedics, EGIS has a "false positive" rate of less than 1 percent, better than other sniffers. The rate has been verified at the Frankfurt/Main Airport in Germany, where 2,500 EGIS screenings are performed each day.

Throughput is the problem. The average analysis takes 18 seconds, and the entire procedure can take several minutes, far below the FAA's threshold.

In November, Thermedics conducted a two-week field test of its first passenger sniffer, the SecurScan, at Boston's Logan International Airport. More than 2,000 travelers volunteered to walk through a portal where 10 wands brushed over their clothing, drawing in an air sample. Three people were stopped: a bomb squad employee, a traveler who had been on a firing range, and an FAA official who had earlier cleaned his gun. SecurScan costs about $300,000.

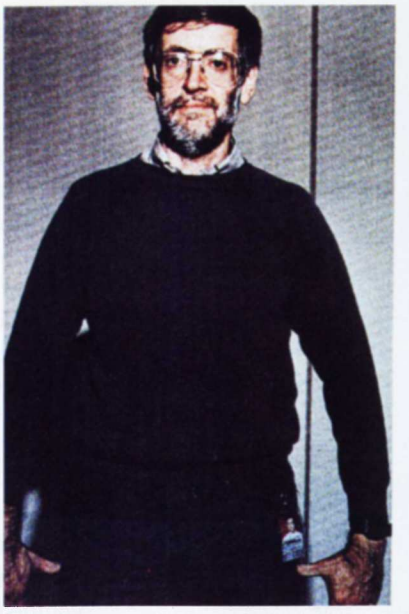
Meticulous terrorists who shower, change clothes, and seal explosives in airtight containers might fool a trace detector. But a unique signature of the explosive might still be "heard" using a novel technique called quadropole magnetic resonance, similar to the magnetic resonance imaging used in medicine.

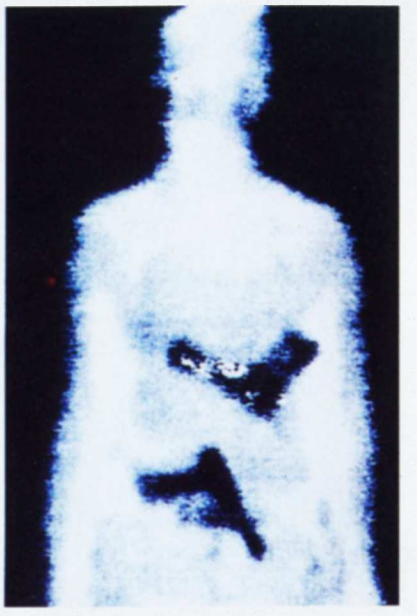
Once inside the QScan-1000, made by Quantum Magnetics in San Diego, a bag is zapped with a pulse of low-

intensity radio waves. Nuclei in the bag and its contents are momentarily tipped out of alignment. As each material realigns, it reradiates a characteristic radio signal, which is picked up by a receiver and compared with the echoes for explosives. If a match is found, a red "fail" light goes on. The company says the process will not damage magnetic media such as computer disks or credit cards.

QScan costs about $300,000 and can inspect some 600 bags an hour. During a week-long trial at Los Angeles International Airport in November, only four false alarms occurred among 4,000 bags, an error rate of 0.1 percent. This newest of the detection technologies works well for plastic explosives, but not for all other types (the echo is not as strong), and the FAA has no certification procedures in place for it yet.

The only other detection technology the FAA has investigated is a scanner that bombards bags with neutrons to sense the density of specific elements, such as oxygen, nitrogen, carbon, and hydrogen. After $20 million in research, the agency has found the hardware to be far too costly, large, and heavy.





MILLITECH'S *Contraband Detection System, which measures natural electromagnetic emissions, can find objects that metal detectors and standard x-rays might miss, such as a 9-millimeter automatic pistol made almost entirely of ceramic (the lower weapon shown). But like all the new systems under study, it has pros and cons: while it avoids exposing passengers to x-rays, it produces grainy images that are sometimes hard to interpret.*

Each of the technologies under consideration can detect explosives, but what matters is how fast and how accurately. Conventional x-ray scanners process 600 bags an hour—six seconds each, on average. The 450-bag-an-hour mark was chosen because anything slower would discourage people from flying, according to Lyle Malotky, science adviser for civil aviation security at the FAA.

While the new x-ray scanners can meet the throughput limit, false alarms are high. Trace detectors are more accurate but need time to analyze samples. And there's the rub: the technologies trade speed for accuracy, or vice versa. The FAA demands both.

Real-life trials point out unforeseen weaknesses. The FAA checks new equipment at its William J. Hughes Technical Center in Atlantic City, N.J., with a standard "test-bag set." Although the CTX-5000 computed-tomography system passed at the Tech Center, its false-alarm rate rose above the FAA limit when used on actual passenger bags at San Francisco Airport. The rate was between 20 and 30 percent, according to Malotky, who is generally regarded as the country's most prominent expert in aviation security. Among the culprits, says Malotky, were certain food products that are similar in shape and density to a ball of plastic explosive and were not included in the FAA's test-bag set.

"False alarms are the bottom line," says Lee Grodzins, professor of physics at MIT and vice-president of AS&E, which makes backscatter x-ray scanners. "Only one bag in a billion might contain a bomb. So in a real airport, every alarm will be a false alarm." Each alarm will require a security guard to search the person or bag, shifting the detection burden to people, which slows the overall movement of passengers and bags. Metal detectors have a 10 percent false-alarm rate, Malotky notes, but most alarms are easy to resolve: just empty your pockets.

Experts acknowledge, too, that each of the new detection methods has an Achilles' heel—some way in which a knowing person can fool the system. Any of the machines might catch a careless terrorist, Grodzins says, "but none of them will stop the Unabomber."

RUNNING THE GAUNTLET

There is no magic bullet. The FAA and the manufacturers are only now accepting the notion that different inspection systems will have to work together, channeling luggage and people through multiple layers of scrutiny. "A gauntlet is really the way to go," says Thermedics president Jeffrey Langan. He is now marketing his EGIS trace detector for examining people already identified as suspicious or for inspecting bags that have triggered alarms in x-ray machines. EG&G and Quantum are jointly producing a large unit that can perform both x-ray and quadropole tests. Quantum will also offer the QScan-1000 as an add-on to an EG&G x-ray baggage scanner; x-rays are still the only way to find metal weapons.

A gauntlet might improve speed as well as detection. Langan figures the new generation of x-ray machines would clear 80 percent of the people and 90 percent of the bags. The remainder would be more closely scrutinized by operators, who might ask passengers to step aside and turn on electronics or open luggage. This would clear all but 1 per-

PHOTO: MILLITECH CORP. / AS&E

cent of the people and bags. These would be analyzed with the more precise but time-consuming trace detectors or quadropole machines. Britain's Heathrow Airport is trying this approach with InVision's CTX-5000 and Thermedics' EGIS machine.

Gauntlets would be costly, since the airlines would have to install several new expensive machines at each checkpoint. Better software would also be needed to coordinate the machines. But ganging machines together could help manufacturers pass FAA criteria. Langan says the FAA "should come up with a standard set of test bags and a dummy with materials hidden under its clothes, give them to the manufacturers, and say, 'You pick your combination of technologies and run these through. If you meet the criteria, you can put this system on the market.' "

LINKING BAGS TO PASSENGERS

Not all solutions to terrorism require state-of-the-art technology. The Gore Commission, which released its final report on February 12, is pushing two decidedly low-tech ideas: bag matching and passenger profiling.

Bag matching could be a powerful deterrent but could prove to be an operational nightmare. Each checked bag is tagged with a bar code that matches a code on its owner's ticket. If the passenger does not board a plane, his or her bags are removed before takeoff. The Lockerbie explosion was caused by a bomb in a piece of luggage that had been checked by a passenger who never boarded. Congress subsequently required the airlines to use bag matching on all international flights. It is not used on domestic flights.

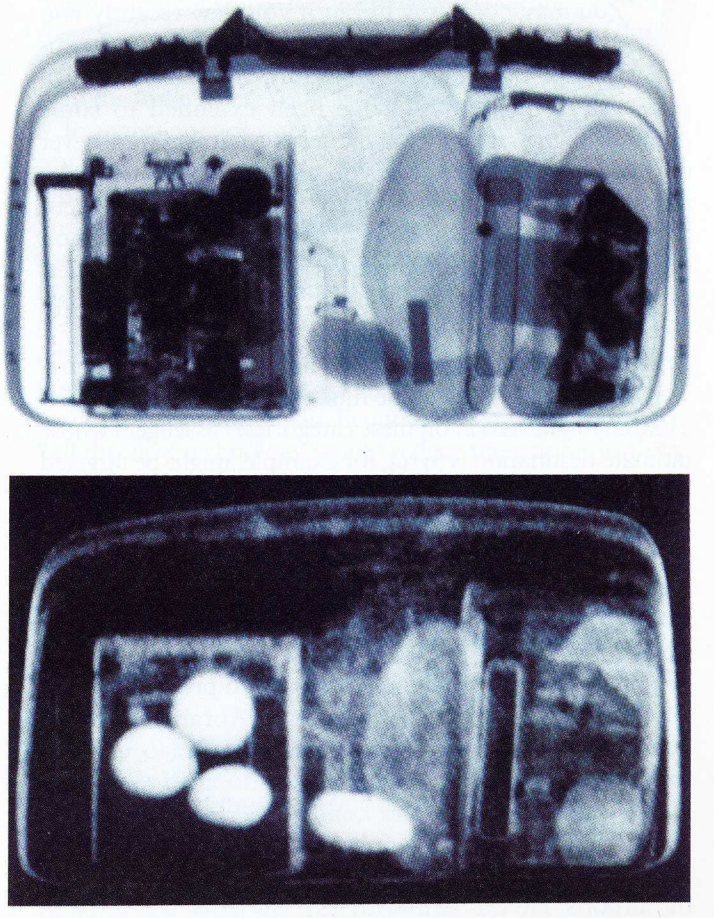
In September, President Clinton directed the FAA to quickly start a month-long bag-matching test at a major hub airport. The airlines objected strenuously on the grounds that bag matching would add significant delay to boarding procedures. Bag matching is doable on international flights because bags must be checked well ahead of boarding, and because there are few tricky connections to coordinate. But in the domestic hub-and-spoke system, which handles 850 million bags a year, connections are frequent and fast. David Fuscus, spokesperson for the Air Transport Association, an airline industry group, says that during peak times at O'Hare, 20 planes dock every 15 minutes. Thousands of passengers race to connecting flights, which depart on the average only 25 minutes later. Tracking every bag, instead of containers of bags, and checking each one against a passenger manifest in that time would be "impossible," Fuscus says.

Furthermore, if a passenger gets sick and must leave the plane, or a late arrival doesn't show, the ground crew would have to tunnel into the plane's luggage bays to find that person's bag, remove it, and resecure the hold. FAA audits indicate that it takes 20 minutes to find and remove this needle in the haystack—if the process is done efficiently. Delays incurred with bag matching could cost the airlines more than $2 billion a year in lost revenue, according to an FAA study.

Bending to airline pressure, the White House agreed to let the FAA stretch out the test program, which it had begun with Northwest Airlines. But the Gore Commission didn't buy the airlines' argument. During a September 1996 press conference on security, Elaine Kamarck, Gore's senior policy adviser, said, "We believe that with technology, some ingenuity, and reengineering we can move to full passenger bag match."

If bags were tagged with disposable radio transmitters, they would be easier to locate once in a cargo hold, according to Jesse Beauchamp, professor of chemistry at the California Institute of Technology. Beauchamp chairs the NRC's Committee on Commercial Aviation Security and is a member of the Gore Commission. There could even be some side benefits, he says: recent tests in Britain have resulted in fewer lost bags.

"Passenger profiling" could also speed up bag match-



BALLS *of simulated plastic explosive that are all but invisible in an ordinary x-ray image (top) show up clearly in an image made by AS&E's "backscatter" x-ray system (bottom). The latter compares reflected x-rays with the signatures of low-density materials such as explosives.*

ing—and the gauntlets—by predetermining which people are suspicious, and thus who should be more closely inspected and which bags should be tracked. By clearing the plainly "innocent" in advance, security people could focus their time and machines on the "unknowns."

Profiling is done by comparing what the airlines know about a passenger against an abstract list of factors that warn of possible danger. A frequent business traveler on his or her usual route might be sent directly to the plane, while a passenger from a country known to support terrorism—and who pays cash for a one-way ticket—will likely be x-rayed and sniffed. Northwest is developing a profiling scheme with FAA funding that would complement its bag-matching plan. The October 9 legislation authorizes the FAA to adapt a system used by Customs officials to zero in on drug traffickers. And the final Gore Commission report urges implementation of some degree of bag matching coupled with passenger profiling by year's end. Gore said bag matching for all luggage is the eventual goal.

THE FOURTH AMENDMENT TEST

You may not know it, but if you flew recently you might already have been profiled. Since the downing of TWA Flight 800 in July, U.S. Customs' profiling procedures have been extended to some domestic flights. If you feel a bit uneasy that you were never told you had been profiled, you have hit upon one of the most critical and widely debated obstacles to better security: the potential violation of civil rights. If detection schemes discriminate on the basis of people's nationalities, or expose too much of their bodies, passengers won't accept them and airlines won't use them.

Even if the profiling criteria do not specify race, religion, or nationality, it doesn't take much imagination to see how a search might zero in on these categories. Passengers whose ultimate destination is Syria, for example, might be targeted because of the country's sponsorship of terrorism. But who flies to Syria besides Syrians? This amounts to de facto discrimination, says Gregory Nojeim, legislative counsel at the American Civil Liberties Union (ACLU) in Washington, D.C. "Reduced to its essentials," he says, "profiling is a stereotype."

Nojeim can cite many horror stories to prove his point. After the Oklahoma City bombing, Abraham Ahmad boarded a plane from that city bound for Chicago, en route to visiting his family in Jordan. He was detained by government agents in Chicago and London and forced to answer questions about his religion, friends, and family members. At various times he was handcuffed and paraded through the airports. He was strip-searched. His name was given to the media, who drove his wife out of their house. All because he "fit the profile" of a terrorist. For similar reasons, Sam Husseini, a consultant to the American-Arab Anti-Discrimination Committee, was singled out and missed flights three times in the summer of 1993 alone.

"When travelers check in at an airline ticket counter," says Nojeim, "they don't check their rights to personal security, privacy, and equality. The Fourth Amendment provides that people and their property shall not be subjected to unreasonable searches and seizures."

The ACLU also maintains that new x-ray techniques constitute an invasion of privacy. Look at the image of the man on this page. Sure, it shows a gun and explosives. It also



MACHINES *that peer through clothing may turn up explosives and weapons, as in this image produced by AS&E's BodySearch system, but such techniques also reveal the naked truth in ways passengers would rather avoid. Image-modifying software could help.*

PHOTO: AS&E

shows his penis. Would you want a similar image of *your* body displayed on a screen for other people to see as you wait to board your flight? "The airport is not a 'no-privacy zone,' " Nojeim says. "We may have catheter tubes in place, evidence of mastectomies, penile implants, and artificial limbs. We expect that we will not be required to show these to others as a condition to boarding an airplane."

The National Research Council agrees. "Displaying an image of the body on a monitor will be a concern to a significant percentage of people," its report concludes.

Problems could be lessened by masking portions of the display, using operators of the same sex as the subjects being scanned, and displaying images in closed monitoring rooms. Each approach would add even more cost, however. Software could help by making a Picasso out of a person being scanned, or by making images generic, but progress has so far been limited. Image recognition software that could discern weapons and explosives without operators would help too, but the amount of artificial intelligence required makes this an even tougher challenge, says MIT's Grodzins.

Though not a civil rights issue, worries about health risks could also make passengers wary. The NRC cites numerous studies indicating that none of the techniques pose health risks to passengers or operators, and that x-ray levels are well within the allowable limits for routine exposure. But both the FAA and the manufacturers acknowledge that some passengers may nonetheless be wary of the new technologies.

AT WHAT PRICE SECURITY?

Even if the technical and social challenges posed by the new technologies can be resolved, costs will have to come down. Most of the detection machines sell for several hundred thousand dollars apiece. Various estimates put the cost to deploy bag scanners alone at the 75 busiest U.S. airports at about $2 billion. That's four times the $500 million in profit the U.S. commercial carriers made in 1995, according to the FAA's Malotky. If a gauntlet were used, the tab would be much higher. And there would still be 300 more airports to go.

Operational costs could be even greater. If slow throughput, false alarms, and bag matching lengthen preboarding time, each airline will schedule fewer flights per day, slowing down the air transportation system. "There are huge feedback effects for even a slight added delay," says Robert Hahn, a regulatory economist at the American Enterprise Institute in Washington, D.C., and author of *Risks, Costs, and Lives Saved* (Oxford University Press, 1996). According to the *Wall Street Journal*, an internal Northwest study concluded that bag matching would add 10 minutes to processing time, a delay that would force the airline to cut its schedule by around 10 percent.

Delay would also hurt the U.S. economy. Adding a half-hour to preboarding time would cost almost $10 billion annually in lost productivity, according to Hahn.

Airports would be pinched, too. More than half their revenue comes from parking and concessions. "More floor space for detection machines means fewer coffee bars," says Malotky, "and longer lines for security checks mean fewer people will have time to buy coffee." Gateways at older airports, already cramped, would have to be expanded and reinforced to support the big, heavy new machines.

All these numbers raise a bald question: Is the price worth paying to save precious, but few, lives? In the past 15 years—a time frame that economist Hahn picks more or less arbitrarily—548 people have died in U.S. airline crashes linked to sabotage (nearly half on Pan Am 103). Dividing this number into the $2 billion needed for bag scanners alone yields a capital cost of $54 million per life saved—if, indeed, the technology could cut bombings to zero.

Whether this is a "good" investment is a distasteful question, but one that government must ask all the time. The money could be used to make safer highways, which are 20 times more dangerous per mile than air travel, according to federal estimates. "We should think about what we're getting for the money," Hahn argues.

Several years ago, the FAA analyzed the idea of requiring children under age two to fly in car seats—instead of sitting on a parent's lap—forcing parents to buy another ticket, then averaging $400. The study showed that more families would drive, which would result in more highway fatalities than the in-flight car seats would save, says Malotky.

In analyzing such tradeoffs, experts are reluctant to quantify how "good" or "bad" the nation's security is. Malotky did say that in the last few years, the airlines have found "fewer than 10" bombs or suspect weapons. Presumably some were missed. Though 100 percent detection is statistically impossible, the process can always improve. But the cost-benefit relationship may run up against diminishing returns. Malotky says if going from 90 to 95 percent detection would cost x dollars, improving from 95 to 98 percent would cost x dollars again. Economist Hahn concludes that "all this new technology would reduce the risk of death by only a very small amount."

The FAA is now developing a cost-benefit analysis. For the time being, Malotky will say only that "if a bombing were to occur every six months, the cost-benefit would certainly make sense. If a bombing took place once every 10 years, it would not make sense." Assuming that terrorism didn't down TWA Flight 800, then the last U.S. airline bombing was Pan Am Flight 103 in 1988. "Despite all the headlines, the chance of getting blown out of the sky is vanishingly small," says George Swenson, professor emeritus of electrical and computer engineering at the University of Illinois and chair of the NRC panel on passenger screening.

Whether heightened security is worth the cost comes down to whether the public perceives a real threat. No one has surveyed passengers to see how they feel.

Still, the technology has intrinsic value as a deterrent. Fighting terrorism is an endless game of threats and countermeasures. "We have no idea how many terrorists have been deterred because they were afraid they'd get caught," says MIT's Grodzins. "Personally, I'd love to see more

bomb-sniffing dogs out there. Nothing is more directly worrisome to a would-be bomber."

Unfortunately, dogs are worrisome to travelers as well. Security experts acknowledge the public's reservations about the military atmosphere that canine teams impart, and about the prospect of being sniffed in sensitive areas by a high-strung Doberman. Dogs also cannot keep up with a systematic, 450-bag-per-hour search regimen. So even though the October 9 legislation encourages the FAA to add as many as 100 canine teams to airports nationwide, it is unclear whether this approach will be a viable substitute for new high-tech detection schemes.

WHO PAYS?

It's also unclear who will end up paying for the latest technology. The actors are in a classic standoff, eyeing each other to see who'll make a move. The airlines are responsible for security, but they don't want to buy advanced equipment if it is not FAA certified; if the FAA mandates a different technology a year later, the airline will have wasted its money. The manufacturers aren't motivated to get certification because they fear the FAA specs will change. The airports have no incentive to take over duties that now fall to airlines. Congress doesn't want to mandate technology.

The irony is that the cost to passengers for better technology would be small. People take about 530 million flights in the United States each year. Raising $2 billion would add $4 a ticket. But even at that price, the financially weak airlines want the government to pay.

Spending tax dollars to buy equipment headed to for-profit companies rankles many Americans. But Grodzins says the public and Congress have to take a broader view. "These attacks are not against Pan Am or TWA," he says, but against the United States. "It is the government's responsibility to fight this war, not the airlines'." The FAA's recent appropriation of $52.2 million to install CTX-5000 scanners may bolster this position.

Thermedics president Langan says the airport authorities should foot the bill, with government funding R&D. "That's how it's done in the rest of the world," he notes. The logic is that security is a policing function that should be performed throughout the airport—not just at airline gates, but at every door—and should be extended not just to passengers, but to every ground-crew member, security guard, and employee of caterers and freight handlers. In the United Kingdom, Langan says, airports have found cost-effective ways of discharging their responsibility for security. Most British airports contract security functions to commercial companies, which purchase better detection equipment and pay and train operators more than the government ever did, because they are competing to provide the best service.

To implement this model, Congress would have to widen the FAA's jurisdiction to include airports. Airports would likely be owned by quasipublic corporations like the Port Authority of New York and New Jersey, which operates Kennedy, LaGuardia, and Newark airports. Evidently, Congress is game. The reauthorization act directs the FAA administrator to report on whether to transfer certain security functions from airlines to airports, and if so, how.

Given the technical, social, and financial issues, some are tempted to wait to deploy a more perfect technology. But Grodzins says the government has already waited too long. "We have a real, live enemy here. We should deploy the best we have, and upgrade it later. We have to put these machines out there to find their real strengths and weaknesses. In the meantime their very presence will deter more terrorists."

A clearer deployment strategy may emerge in the next few months. In February, President Clinton urged Congress to approve an additional $100 million a year to implement recommendations of the Gore Commision. By June, the National Research Council will issue its second annual report, which will advise the FAA on what to implement. And the year-long trial of hundreds of machines sprung by the October 9 appropriation will soon be in full swing.

In order for new technology to do its job properly, some other holes in airport security will have to be plugged. A moderate-sized airport is a veritable sieve, with more than 200 doors and passageways; many security experts say they have wandered into restricted areas unencumbered. In addition, no technologies or procedures are in place for inspecting mail or freight, and none are planned. NRC panel chair Swenson adds that "background checking of airline and airport employees, and potential new hires, is also loose."

Another problem area is operator training. The NRC feels operators could be the weakest link in future systems. "Low wages, high turnover, inadequate training, and poor working conditions need to be addressed," security committee chair Beauchamp told Congress in September.

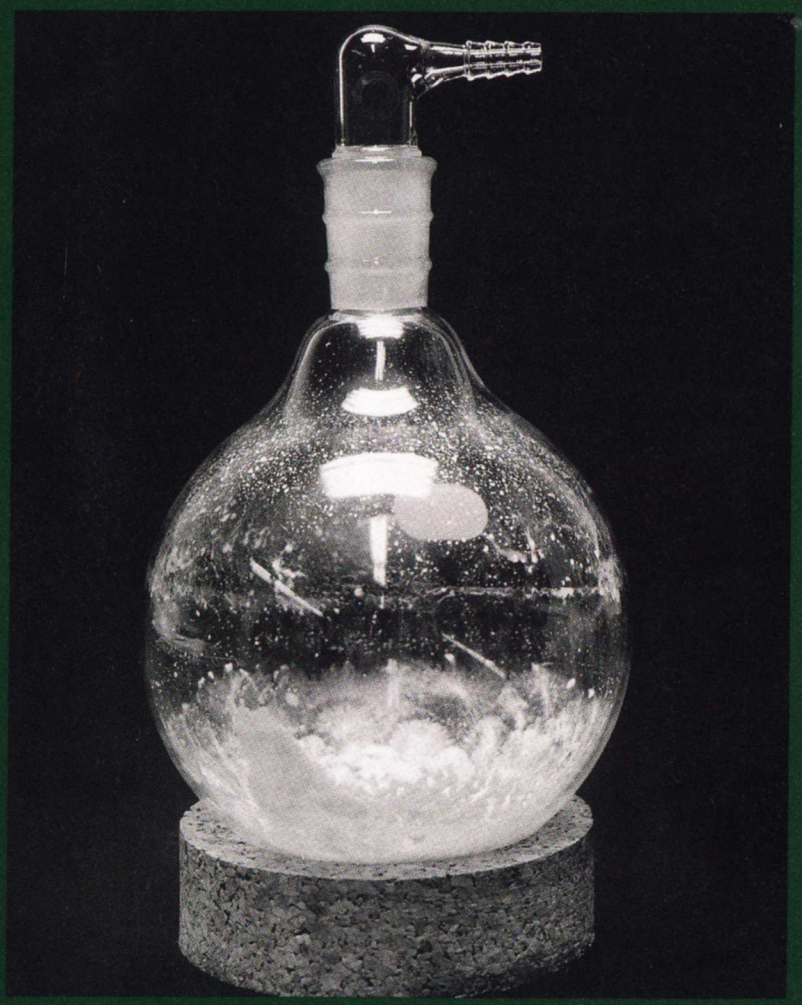
Maintaining tight security also depends on testing the system. The FAA uses "red teams" to try to foil security at random airports. They have sneaked suspicious packages, fake bombs, and weapons past guards and x-ray machine operators, then reported back to the airline that security had better shape up. But the FAA needs to watch its own back. A 1996 audit by the Department of Transportation's inspector general on red team activities at 26 airports revealed that a few FAA special agents appeared to tip off airline personnel, or failed to report breeches of security, perhaps because of quid-pro-quo deals with airline employees.

It's too early to predict when new technology may be permanently installed. Although the October 9 appropriation jump-starts the process, it could fizzle. "The FAA pays a lot of attention to the political winds," says MIT's Grodzins. "Manufacturers have gotten burned before. Lots of legislation was rapidly passed after the 1988 Pan Am bombing, but we're still using the same technology on domestic flights now as we were using the day before it happened."

So the standoff may continue until Congress commands the FAA to require new technology. What would prompt legislators to do so? George Swenson fears the simple, terrible answer: "A few more bombings."■

By Cornelia Homburg

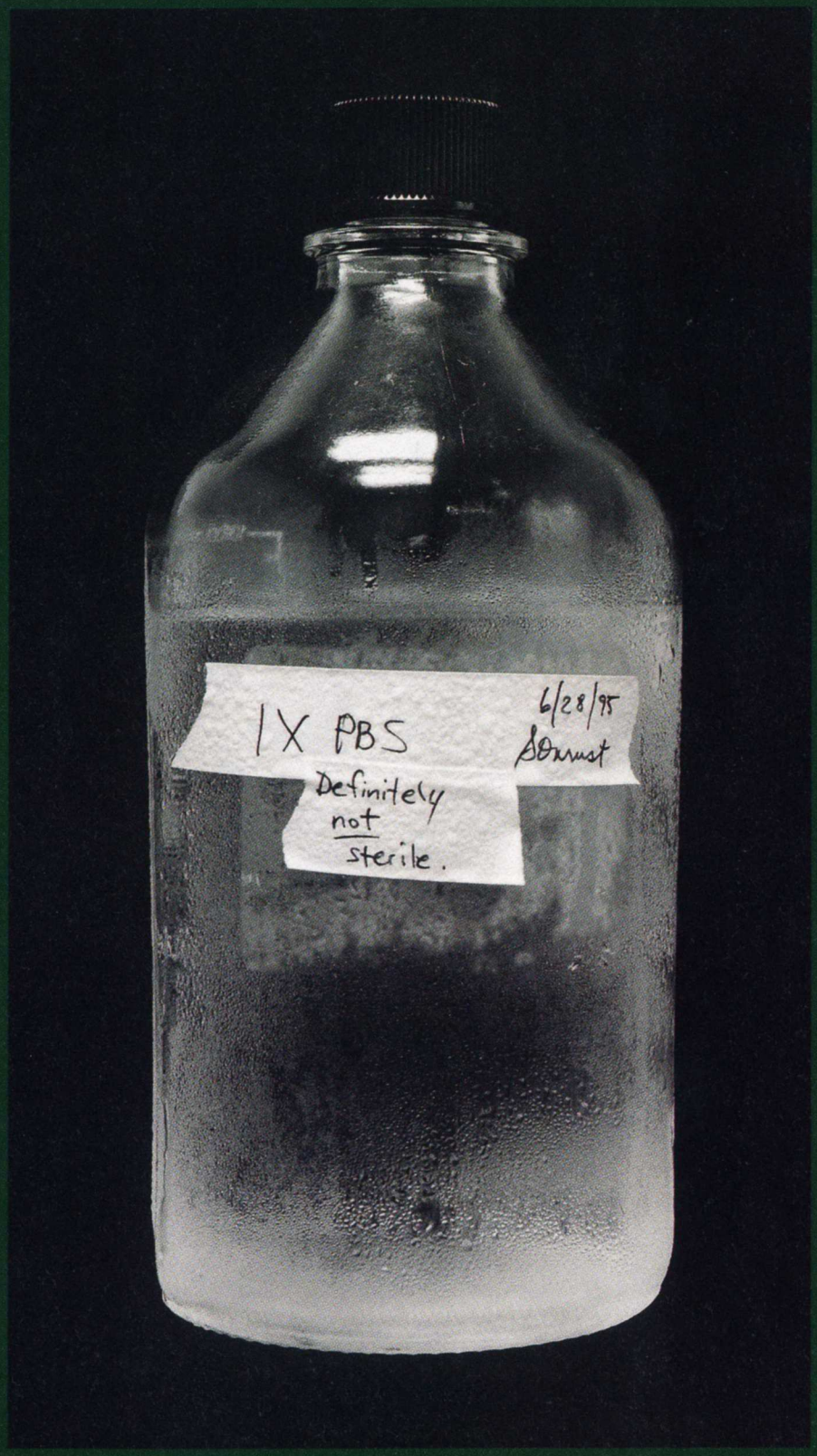
An Artist Explores the Lab

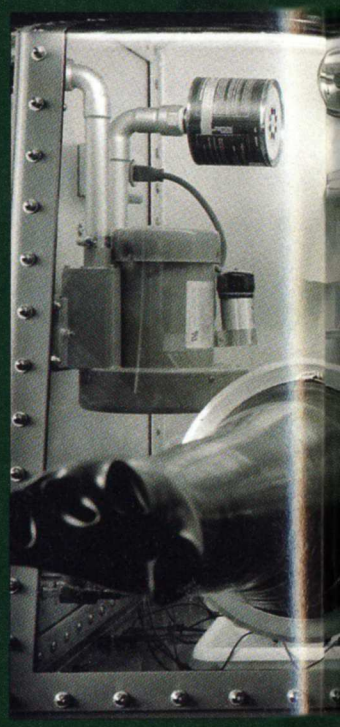


Sequential Molecules, 1995

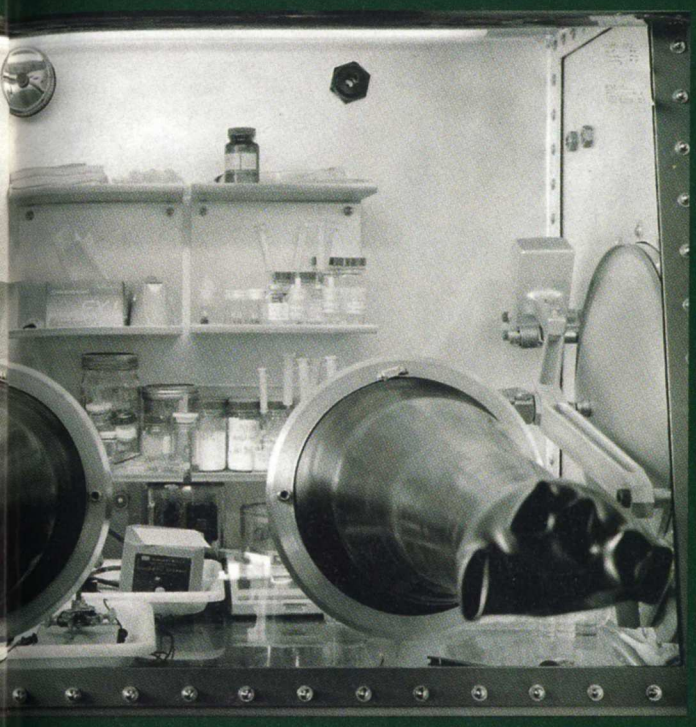
A recent photography exhibit goes behind the closed doors of major laboratories to shed fascinating light on the research shaping modern life.

PHOTOGRAPHS BY CATHERINE WAGNER





DEFINITELY NOT STERILE, 1995



GLOVE BOX, 1993

The pristine quality
nd analytical clarity of
Vagner's photographs
echo the orderliness
of the lab.

AN awareness of the decisive influence that scientific insights and technological advances exert on our lives led San Francisco photographer Catherine Wagner to undertake an unusual project. She entered major U.S. research laboratories and photographed the world she found there, focusing on simple, auxiliary objects as well as highly sophisticated instruments. The result of these efforts is *Art & Science: Investigating Matter*, an exhibition that was organized by the Washington University Gallery of Art in St. Louis and will be on display at New York City's International Center of Photography from March 28 to June 15. Wagner's photographs offer the opportunity to encounter science in an innovative and unusual manner, as they not only cover various fields of research, such as molecular biology, physics, and earth and planetary science, but they also bridge the distance between art, science, and everyday life. While the photographs are an inquiry into the overall concept of scientific research, they live as works of art on their own, too.

Wagner's approach to her topic becomes apparent in the choice of her subject matter, the form in which she presents her imagery, and the level of involvement she allows herself in arranging her objects. In order to avoid any interest in or identification with the individual, Wagner excludes people from her images and records only the results of human activity. Her principle of concentrating on the work of her fellow beings, as opposed to their personalities or appearances, is illustrated most forcefully in an image like *Glove Box*. It is clear from this photograph that someone has been doing work in

CORNELIA HOMBURG is curator of modern art at the Saint Louis Art Museum and the author of The Copy Turns Original: Vincent van Gogh and a New Approach to Traditional Art Practice *(Benjamins Publishers, 1996).*

All photographs copyright Catherine Wagner, courtesy Fraenkel Gallery, San Francisco.

the sterile interior of the box, but now the gloves thrust out at the beholder are empty. The somewhat startling frontal view of the apparatus emphasizes the absence of the person who has conducted the research.

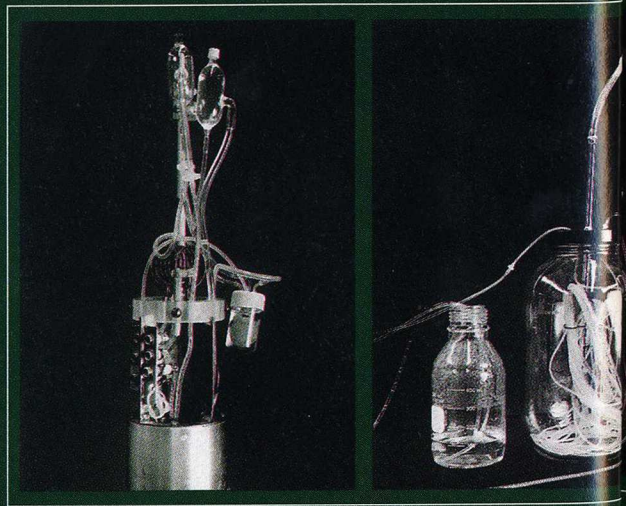
The pristine quality and almost analytic clarity of Wagner's photographs echo the orderliness of the lab and the precision with which data are recorded. The rows of petri dishes in *Mating Reactions of Algae* bring to mind the repetitiveness of investigations—the meticulously controlled trials executed over and over with ever-so-slight variations. The gleaming robot-like technology shown in *Ultra High Vacuum Chamber* characterizes the highly advanced equipment on which much scientific research depends. And photographs of objects that carry a scrupulous identification of their sterile or unsterilized state stress the painstakingly maintained hermeticism that is a banal but vital part of so much laboratory work.

Yet despite the artist's clinical approach, her work also expresses a very personal viewpoint. In *Sequential Molecules*, for instance, the flasks have a kind of shimmering perfection that results from careful staging: the photographer uses a smooth, black backdrop and skillful lighting to present each one in its most alluring form. Some bottles are seen in profile while others are viewed head on, recalling the tradition of portraiture in which the sitter is presented in his or her most advantageous position. The actual contents of the images—the molecules fabricated by humans for use in experiments—seem to exemplify the control people have over nature, but the viewer almost overlooks them for the marvel of the flasks, whose beauty suggests the attraction that such power holds.

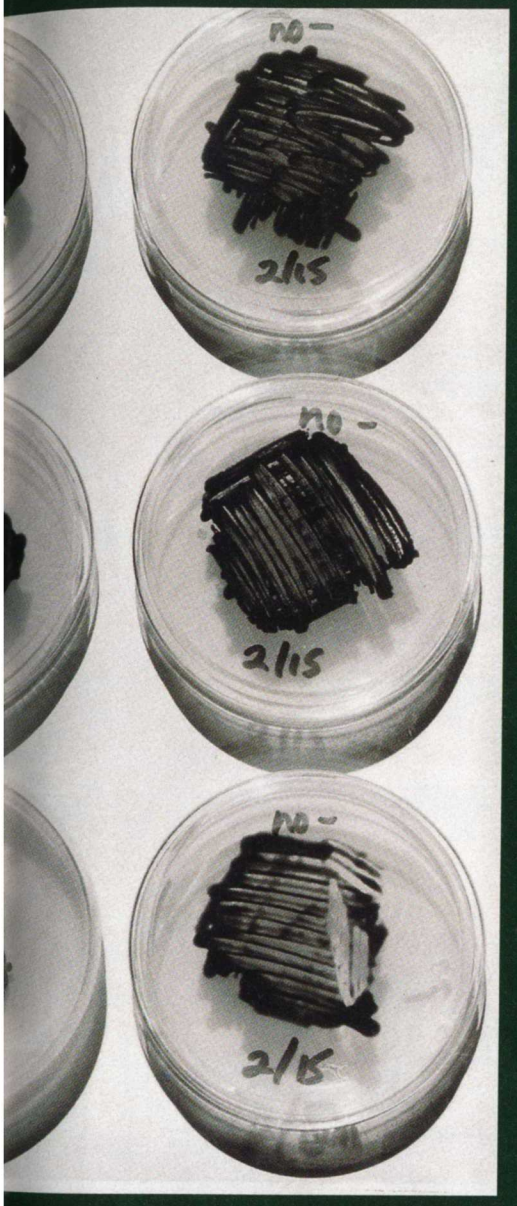
This combination of methodical, categorizing observation with an evocative visualiza-



MATING REACTIONS O

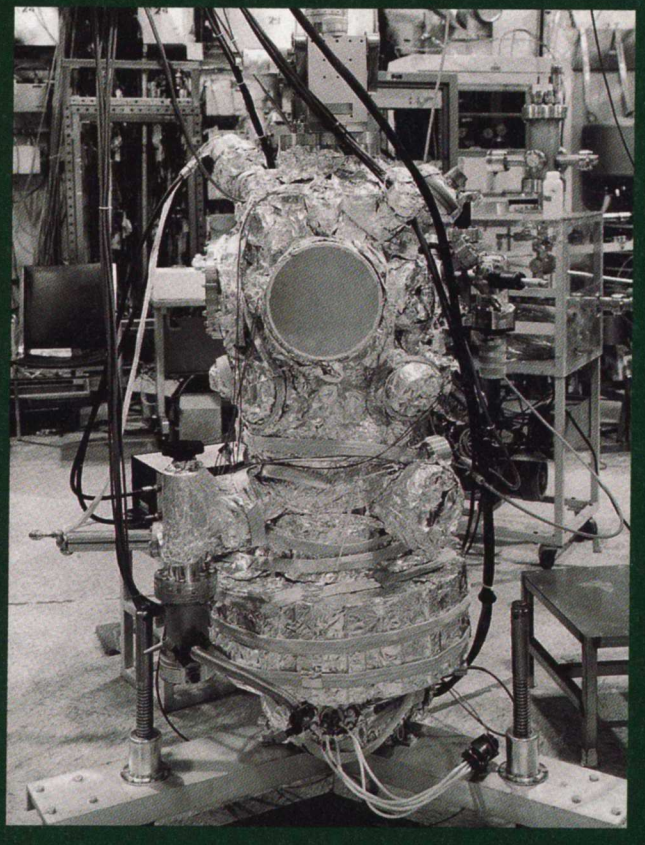


BEATING HEART—HEART CHAMBER, 19

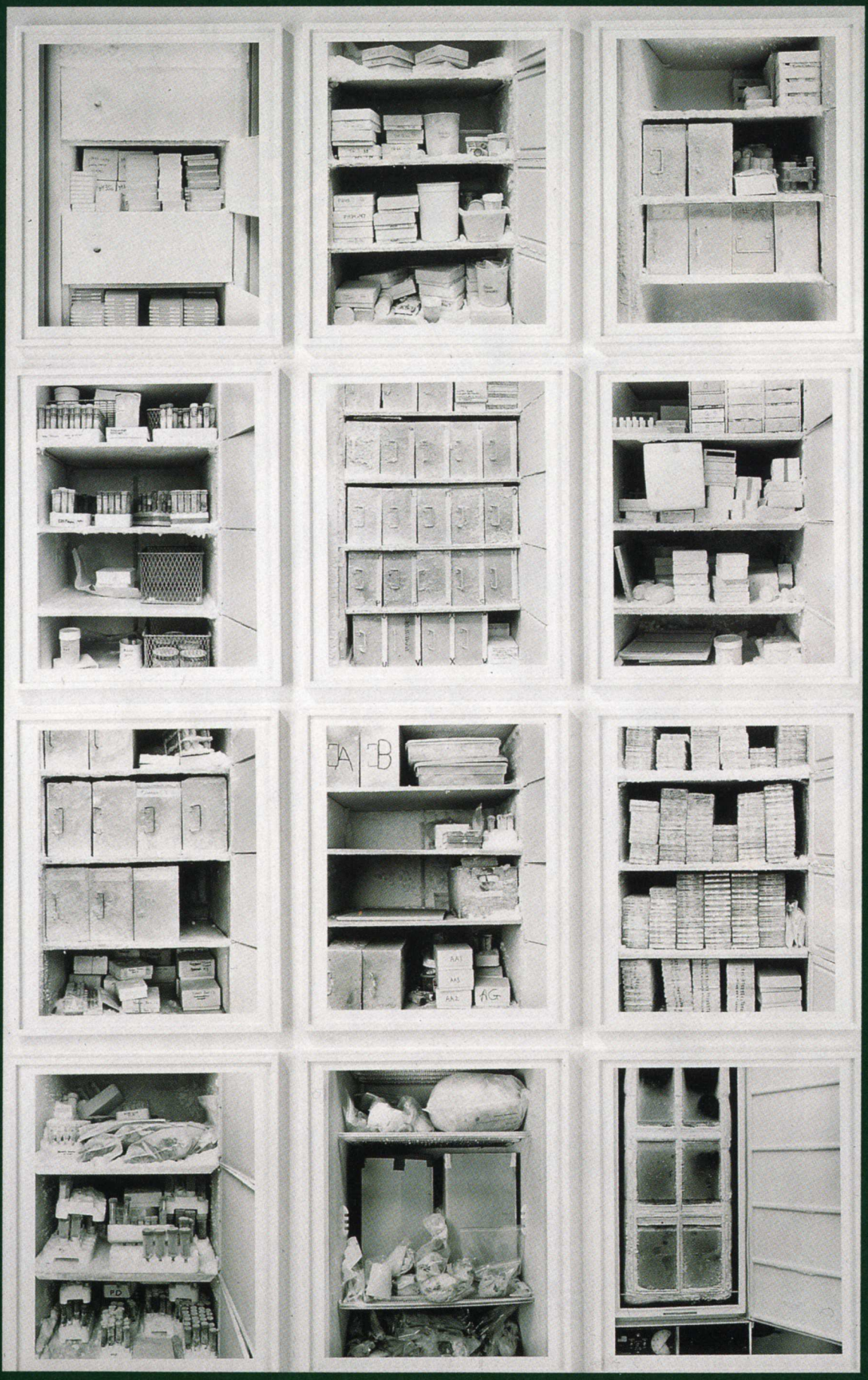


ALGAE, 1995

Wagner allows us to contemplate the beauty of her images yet invites us to consider the enormous impact of her subject matter.



ULTRA HIGH VACUUM CHAMBER, 1992



DNA CLONE LIBRARY

COLON CANCER

HUMAN GENOME PROJECT

BIPOLAR DISORDER

HIV

BREAST CANCER

THYROID CANCER

ALZHEIMER'S

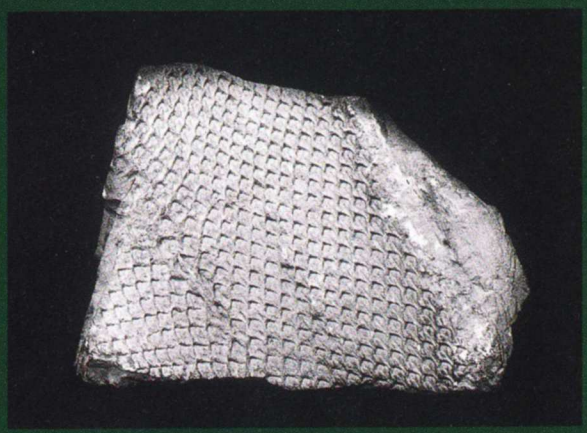
MEGA-YAC LIBRARY

ALCOHOLISM

TISSUE

-70° FREEZER

-86° Freezer, 1995





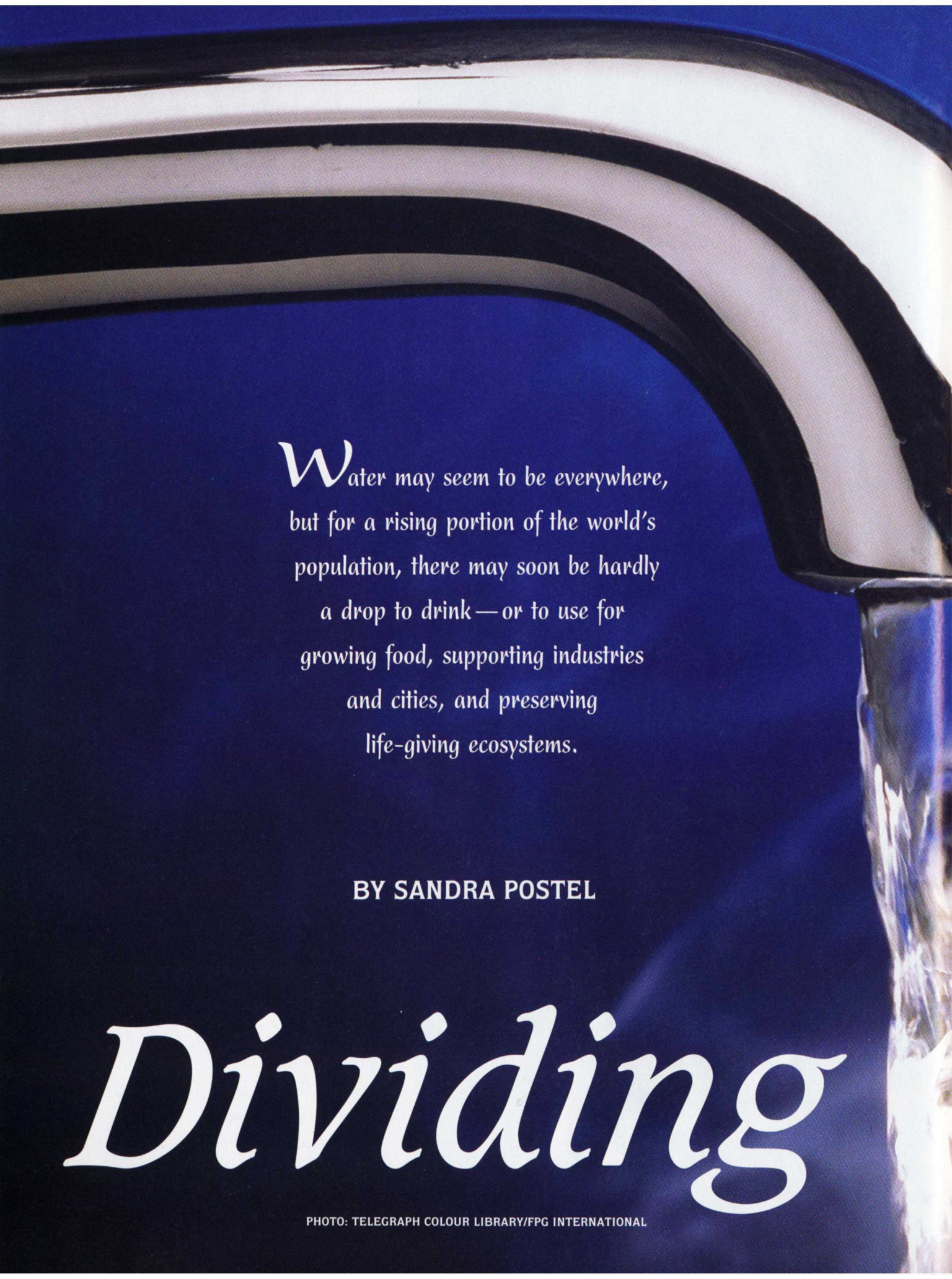
FOSSILS, 1995

To avoid any interest in the individual, Wagner excludes people from her images and records only the results of human activity.

tion is employed to produce vastly different effects throughout the body of Wagner's work. Two groups of photographs, *-86 Degree Freezers* and *Fossils*, exemplify that range. The grid of *-86 Degree Freezers* yields chilling associations, both literally and figuratively. The direct, frontal view does not allow for pleasurable contemplation, nor does the repetitiveness of the 12 white, ice-encrusted interiors combined with the precise information of what they contain—materials related to research on both the human genome and illnesses such as Alzheimer's, cancer, and AIDS. Presentation and content combine to confront us with a sense of the nature of crucial medical studies.

In direct contrast to the *Freezers*, the *Fossils* create a more mysterious atmosphere. While the freezer images are visually thrust upon the viewer, the fossils seem to float across their black background, evoking a reflective mood and putting the contemporary human endeavors depicted in other images into historical perspective. Such a black background is also used very effectively in *Beating Heart—Heart Chamber*, where thin tubes are coiled inside of shimmering glass bottles on the right, while an apparatus on the left keeps a small heart artificially beating in a container. The instruments stand out starkly against infinite blackness.

Wagner's sensitivity to the forces that shape modern life has been a thread throughout much of her previous work, but it reaches a new level of intensity in this project. She allows us to contemplate the aesthetic beauty of her images and invites us at the same time to consider the enormous impact her subject matter—science—has on our lives. ❖

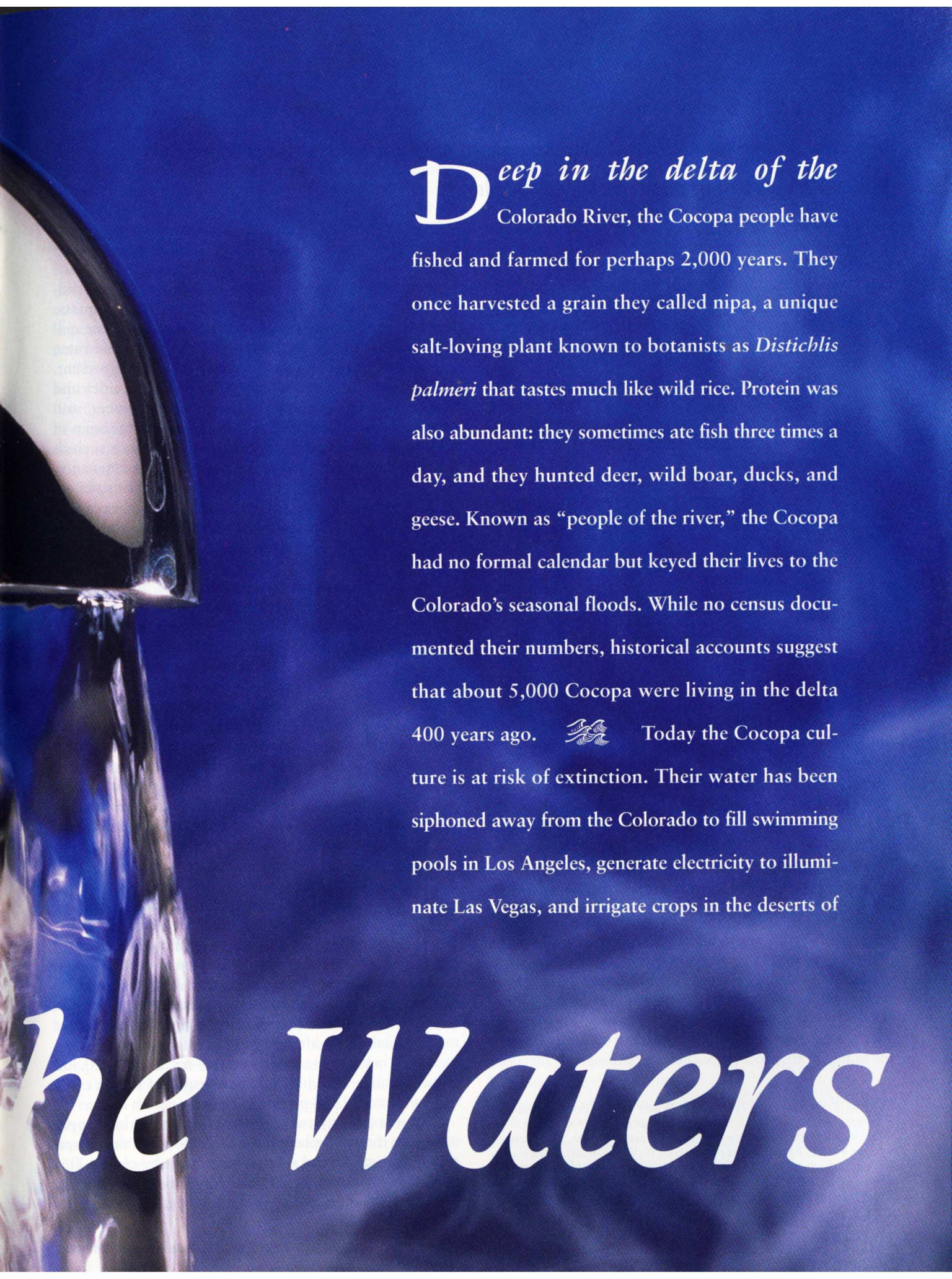


Water may seem to be everywhere, but for a rising portion of the world's population, there may soon be hardly a drop to drink—or to use for growing food, supporting industries and cities, and preserving life-giving ecosystems.

BY SANDRA POSTEL

Dividing

PHOTO: TELEGRAPH COLOUR LIBRARY/FPG INTERNATIONAL

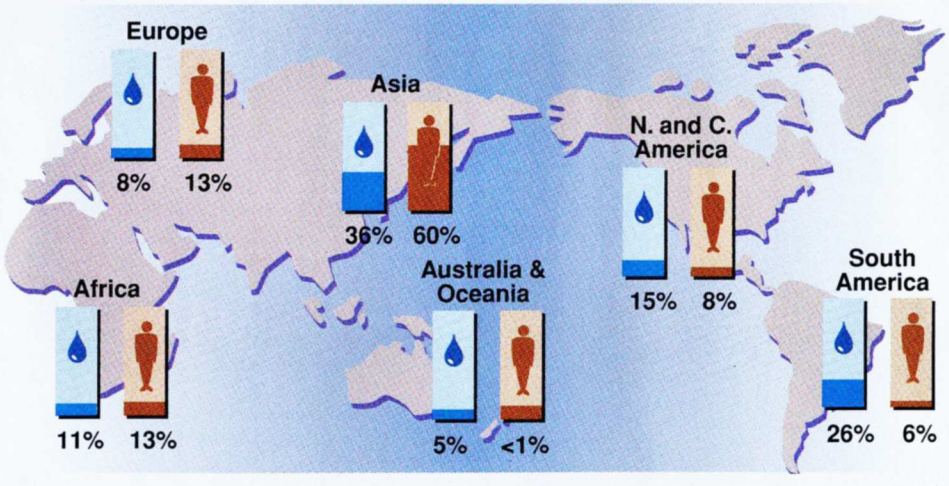


Deep in the delta of the Colorado River, the Cocopa people have fished and farmed for perhaps 2,000 years. They once harvested a grain they called nipa, a unique salt-loving plant known to botanists as *Distichlis palmeri* that tastes much like wild rice. Protein was also abundant: they sometimes ate fish three times a day, and they hunted deer, wild boar, ducks, and geese. Known as "people of the river," the Cocopa had no formal calendar but keyed their lives to the Colorado's seasonal floods. While no census documented their numbers, historical accounts suggest that about 5,000 Cocopa were living in the delta 400 years ago. Today the Cocopa culture is at risk of extinction. Their water has been siphoned away from the Colorado to fill swimming pools in Los Angeles, generate electricity to illuminate Las Vegas, and irrigate crops in the deserts of

he Waters

From space, the earth looks like a huge ball of water. Yet the renewable supply of freshwater—that available to meet human needs on a sustainable basis—totals just 0.008 percent of all the water on the planet.

Arizona, California, and Mexico's Mexicali Valley. Fishing and farming can no longer sustain them. They last harvested nipa in the early 1950s; by then, U.S. dams upstream had largely eliminated the annual floods that had naturally irrigated their staple grain. Now just 40 to 50 Cocopa families remain south of the border. With little means of subsistence or livelihood in the delta countryside, many of the tribal members have migrated to the cities. Anita Alvarez de Williams, a Mexicali-based expert on the Cocopa, worries that by the end of the twentieth century they "may no longer be river people at all."



SHARE OF GLOBAL RUNOFF VS. SHARE OF GLOBAL POPULATION

Nature's delivery of freshwater correlates poorly with the distribution of world population. Asia, for example, receives 36 percent of global runoff but is home to 60 percent of the world's people, while South America receives 26 percent of the runoff for just 6 percent of the population.

It might be tempting to dismiss the Cocopa's plight as the price of progress. Supporting ever larger populations and higher levels of consumption has always involved taking more and more of nature's bounty, and those last in line are bound to suffer. But apart from the tragedy of losing yet another culture in a world of dwindling cultural diversity, the fading of the Cocopa people is a harbinger of far more widespread disruption to society at large today.

Indeed, a growing scarcity of freshwater is now an impediment to global future food security, health of aquatic ecosystems, and social and political stability. Each year, millions of tons of grain are grown by depleting groundwater, a clear case of robbing the future to pay for the present. Competition for water is increasing—between cities and farms, between neighboring states and provinces, and between nations—as demands bump up against the limits of a finite supply. And critical ecosystem functions such as flood protection, water purification, habitat maintenance, and the sustenance of fisheries are being destroyed by excessive damming, diversion, and pollution of rivers.

As world population expands by a projected 2.6 billion people over the next 30 years, and as consumption levels spiral upward, water problems are bound to intensify. With the best dam sites already developed and many rivers and groundwater reserves already overtapped, opportunities to solve these problems by exploiting new sources are limited. A fresh approach is needed, one focused on using water more efficiently and allocating it more equitably.

Global Mirage

The photographs of earth taken by astronauts show a strikingly blue planet, seemingly a world of water spinning in space. Yet this impression of water wealth may be as deceptive as a desert mirage. Only about 2.5 percent of all the water on earth is fresh, and two-thirds of that is locked in glaciers and ice caps. The renewable freshwater supply on land—that made available year after year by the solar-powered hydrologic cycle in the form of precipitation—totals some 110,300 cubic kilometers (1 cubic kilometer equals 1 billion cubic meters), a mere 0.008 percent of all the water on earth.

Each year, nearly two-thirds of this renewable supply returns to the atmosphere through evaporation or transpiration, the uptake and release of moisture by plants. This process supplies the water needed for forests, grasslands, rain-fed croplands, and all other nonirrigated vegetation.

SANDRA POSTEL directs the Global Water Policy Project based in Amherst, Mass. She was formerly vice-president for research at Worldwatch Institute, where she remains a senior fellow. She is author of Last Oasis: Facing Water Scarcity *(W.W. Norton), which also served as the basis for a documentary to air on PBS in July. This article is adapted from her recent Worldwatch paper* Dividing the Waters: Food Security, Ecosystem Health, and the New Politics of Scarcity.

DIAGRAMS BY MICHAEL PRENDERGAST

The remainder, just over one-third of the renewable supply—about 40,700 cubic kilometers per year—is runoff, the flow of freshwater from land to sea through rivers, streams, and underground aquifers. This is the source for all human diversions or withdrawals of water—for irrigated agriculture, industry, and households as well as a variety of "instream" water services, including the dilution of pollutants, navigation, and the generation of hydroelectric power. Rivers also carry nutrients from the land to the seas and in this way help support the highly productive fisheries of coastal bays and estuaries. Thus, by virtue of the hydrologic cycle, the oceans water the continents, and the continents nourish the oceans.

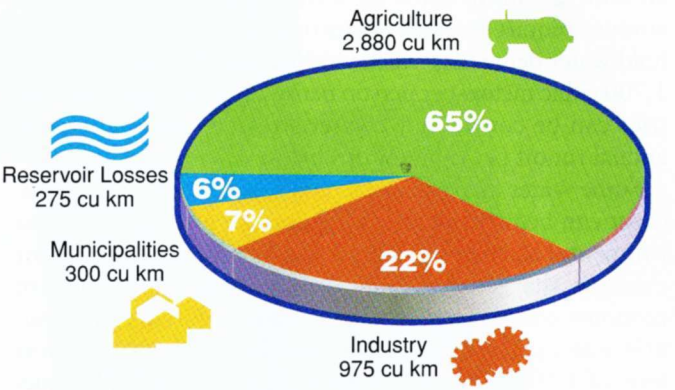
Though the volume of runoff seems huge, nature's delivery of this freshwater supply does not correlate well with the distribution of world population. Asia, for example, receives 36 percent of global runoff but is home to 60 percent of the world's people; South America, on the other hand, supports 6 percent of the population yet has 26 percent of the world's runoff. The Amazon River alone carries 15 percent of the earth's runoff but is accessible to only 0.4 percent of the world's population. Much of the river flow in the tropics and high latitudes is virtually inaccessible to people and economic activity and is likely to remain so for the foreseeable future, since water is difficult and expensive to transport long distances. In fact, 55 rivers in northern North America, Europe, and Asia, with combined annual flows equal to about 5 percent of global runoff, are so remote that no dams have been constructed on them, even for hydropower.

According to a 1996 study conducted by this author and Gretchen Daily and Paul Ehrlich of Stanford University, the total amount of runoff within reach geographically totals some 32,900 cubic kilometers or about 81 percent of the total runoff. But that's not the end of the story. About three-fourths of this amount is flood water and therefore not accessible on demand when it is needed most. To add to the remaining one-fourth that is accessible, engineers have built large dams and reservoirs, raising the stable supply of water provided by underground aquifers and year-round river flows by about half. This brings the total stable renewable supply to 12,500 cubic kilometers.

Globally, people now use about 35 percent of this accessible supply, or some 4,430 cubic kilometers per year. At least an additional 19 percent is used "instream" to dilute pollution, sustain fisheries, and transport goods. Thus humanity is already appropriating, directly or indirectly, more than half of the water supply that is now accessible. The problem is that water use tripled between 1950 and 1990 as world population soared by some 2.7 billion. Given that the population is projected to climb by nearly the same amount over the next 30 years, this is a troubling prospect. Worldwide demand for water cannot triple again without causing severe shortages for crop irrigation, industrial use, basic household needs, and critical life-supporting ecosystems.

Water Stressed

The scarcity of renewable freshwater not only poses a long-term threat but has already begun taking a toll in many countries, especially where population has grown out of proportion to water resources. The United Nations Food and Agriculture Organization estimates that producing the food needed for a nutritious, low-meat diet requires about 1,600 cubic meters of water per person per year. In humid climates, virtually all of this could be provided directly to the soil by natural rainfall. But in drier regions and in those with distinct wet and dry seasons, a portion of the needed moisture would have to be supplied by irrigation water drawn from rivers, lakes, or aquifers. Estimating conservatively that a third of the 1,600 cubic meters per person would need to be supplied by irrigation, annual water demand for food—above and beyond what direct rainfall provides—would average about 530 cubic meters per person.



ESTIMATED GLOBAL WATER DEMAND AND CONSUMPTION

Crop production is highly water intensive, accounting for nearly two-thirds of all the water removed from rivers, lakes, and aquifers for human activities. Moreover, whereas a large portion of the water used in homes and factories is recycled, half to two-thirds of agriculture's share is lost through evaporation and transpiration.

Of course, countries have more than just food needs to meet. Estimates by Russian hydrologist Igor Shiklomanov suggest that worldwide household, municipal, and industrial water uses average about 240 cubic meters per capita per year. More widespread use of efficient technologies could reduce this level substantially, but the resulting savings would partially be offset by the more than 1 billion people now lacking minimum household water supplies and by rising affluence, which translates into higher water use. Assuming an average for household, municipal, and industrial uses of 200 cubic meters per capita per year, and adding this to the freshwater required for food production, yields a requirement of some 730 cubic meters per capita per year.

Unfortunately, in many, if not most, countries it is difficult to access and control more than 30 to 50 percent of runoff. Moreover, a portion of runoff must remain in rivers to dilute

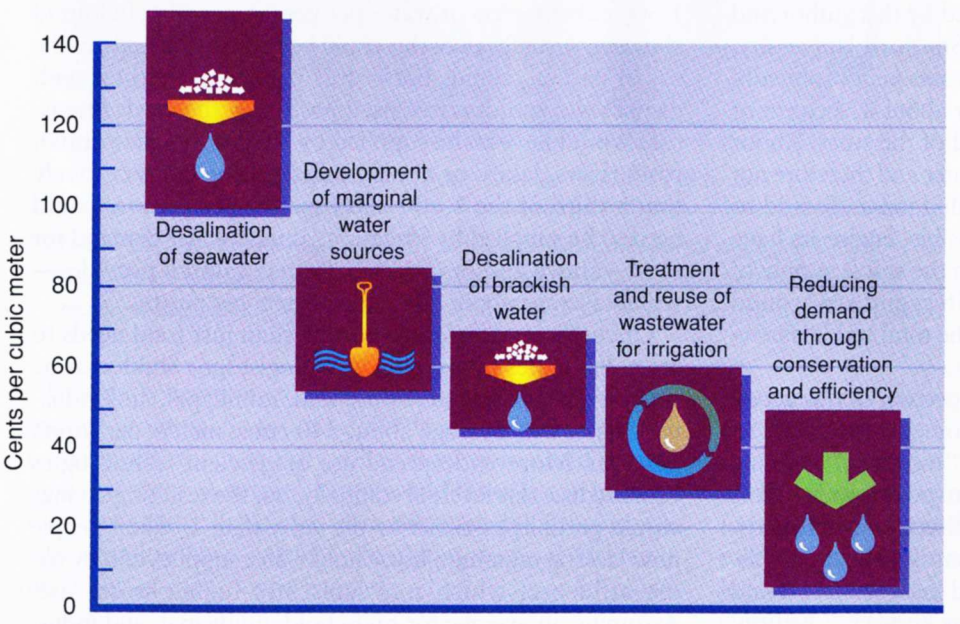
More than 40 countries are considered "water stressed" because they lack access to a sufficient amount of water—1,700 cubic meters per person per year—to meet irrigation, industrial, and household water needs.

pollution and satisfy other "instream" needs. Thus the total amount of runoff must be 2 to 3 times higher than the amount required to meet irrigation, industrial, and household water demands, which works out to be approximately 1,700 cubic meters per person per year. Consequently, countries can be considered "water stressed" when the total annual runoff per capita drops below 1,700 cubic meters.

Some water analysts argue that this "water stress" indicator can be misleading. Hillel Shuval, professor of environmental science at Hebrew University, points out, for example, that Israel maintains a highly successful modern economy and high per-capita income even though its renewable water per person is less than a fifth of the water-stress level of 1,700 cubic meters per year. In part, Israel has succeeded so well with its limited supplies by importing much of its grain—which Shuval and others sometimes refer to as "virtual water."

Indeed, with the production of each ton of grain requiring some 1,000 tons of water, importing grain becomes a key strategy for balancing water budgets. Such a strategy would seem to make economic and environmental sense for countries short of water, since they can get much higher value from their limited supplies by devoting them to commercial and industrial enterprises and using the resulting income to purchase food through international markets. The Middle East, for instance, which is the most concentrated region of water scarcity in the world, imports 30 percent of its grain. As long as surplus food is produced elsewhere, nations with surpluses are willing to trade, and the countries in need can afford to pay for the imports, it would seem that water-short countries can have food security without needing to be food self-sufficient.

This tidy logic is shaken, however, by the growing number of people living in countries where water availability is a constraint to food self-sufficiency, and by widespread signs of unsustainable water use in key food-producing regions. As of 1995, a total of 44 countries with a combined population of 733 million people had annual renewable water supplies per person below 1,700 cubic meters. Just over half of these people live in Africa or the Middle East, where the populations of many countries are projected to double within 30 years. Water-short Algeria, Egypt, Libya, Morocco, and Tunisia are each already importing more than a third of their grain. With their collective population projected to grow by 87 million people over the next 30 years, these countries' dependence on grain imports is bound to increase. Indeed, this is a likely scenario for much of Africa: given current population projections, more than 1.1 billion Africans will be living in water-stressed countries by 2025—three-quarters of the continent's projected population.



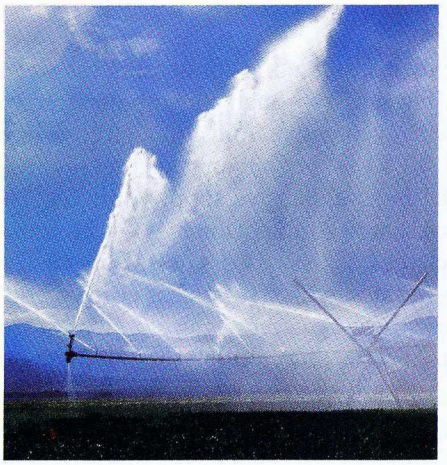
ESTIMATED COSTS OF WATER MANAGEMENT OPTIONS

Conservation options—including repairing leaks, adopting new technologies, and recycling water—range in cost from 5 to 50 cents per cubic meter, less than most methods of developing new freshwater supplies, and far less than desalinating seawater.

Portions of many large countries, including China, India, and the United States, would also qualify as water stressed if breakdowns of water supplies and population were available by region. Even using national statistics, China—with 7 percent of global runoff but 21 percent of world population—will narrowly miss the 1,700 cubic meter per capita mark in 2030; India, the world's second most populous country, will join the list by then.

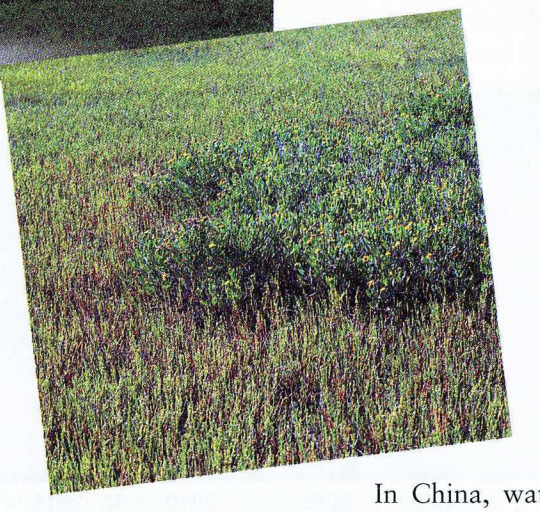
Water for Food

Many physical signs of unsustainable water use authenticate the numerical indicator of water stress. Perhaps most important, evidence





Water-wise irrigation: Farmers who switch from sprinkler irrigation (far left) to systems that meter out water more efficiently (near left) can cut water use by 25 percent or more. Some farms can also conserve freshwater by using saltwater to irrigate salt-tolerant crops such as Salicornia (below), a high-yield oilseed-bearing plant.



suggests that the amount of freshwater that can sustainably be supplied to farmers is nearing its limit. Groundwater overpumping and aquifer depletion are now occurring in many of the world's most important crop-producing regions—including the western United States and large portions of India, as well as parts of north China, where water tables are dropping 1 meter a year. This signals not only that limits to groundwater use have been exceeded in many areas, but also that a portion of the world's food supply is produced through unsustainable water use.

Like groundwater, many of the planet's major rivers are suffering from overexploitation. In Asia, where the majority of world population growth and additional food needs will be centered in the years ahead, many rivers are completely tapped out during the drier part of the year, when irrigation is essential. These include most rivers in India—among them the mighty Ganges, a principal water source for densely populated and rapidly growing South Asia, and China's Yellow River, whose lower reaches ran dry for an average of 70 days a year in each of the last 10 years and for 122 days in 1995. Demand for water is exceeding the Yellow River's capacity to supply it.

Crop production may be even harder hit in these and other areas as population growth and urbanization push up water demands. Worldwide, the number of urban dwellers is expected to double to 5 billion by 2025. With political power and money concentrated in the cities, and with insufficient water to meet all demands, governments will face strong pressures to shift water out of agriculture even as food demands are rising.

In fact, the reallocation of water from farms to cities is well under way in both industrial and developing countries. In California, for instance, a 1957 water plan projected that 8 million hectares of irrigated land would ultimately be developed statewide, yet the state's irrigated area peaked in 1981 at 3.9 million hectares, less than half this amount. Net irrigated area fell by more than 121,000 hectares during the 1980s. California officials project an additional net decline of nearly 162,000 hectares between 1990 and 2020, with most of the loss owing to urbanization as the population expands from 30 million to a projected 49 million.

In China, water supplies are being siphoned away from farmlands surrounding Beijing to meet that city's rising domestic, industrial, and tourist demands. The capital's water use now exceeds the capacity of its two main reservoirs, and farmers in the agricultural belt that rings the city have been cut off from traditional sources of irrigation water. With some 300 Chinese cities now experiencing water shortages, this shift is bound to accelerate.

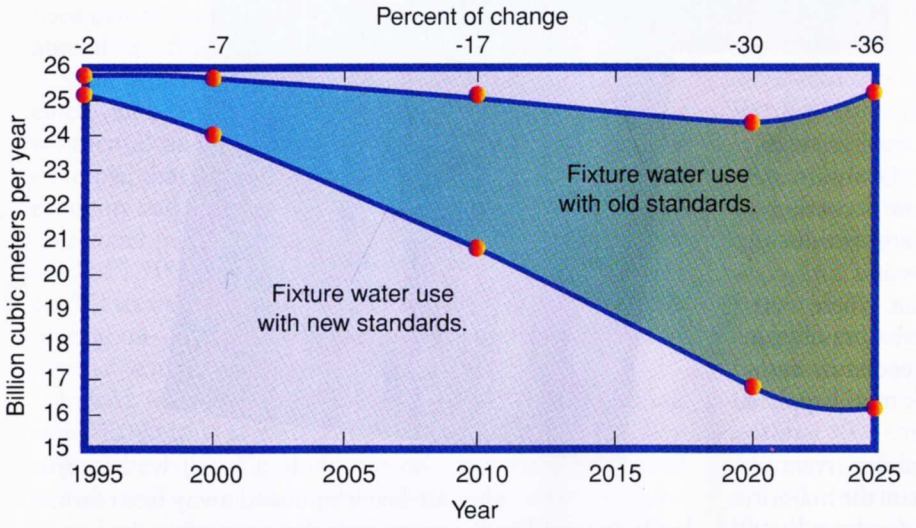
Similarly, growing demand in the megacities of Southeast Asia—including Bangkok, Manila, and Jakarta—is already partially met by overpumping groundwater. With limited new sources to tap, pressures to shift water out of agriculture will mount in these regions as well.

Unfortunately, no one has tallied the potential effect on future food production of the progressive shift of water from agriculture to cities combined with groundwater overpumping, aquifer depletion, and the other forms of unsustainable water use. Without such assessments, countries have no clear idea how secure their agricultural foundations are, no ability to accurately predict their future food import requirements, and no sense of how or when to prepare for the economic and social disruption that may ensue as farmers lose their water.

Supply-Side Options

Preventing water scarcity from undermining food security, ecological life-support systems, and social stability will not be easy. In much of the world, expanding the water supply for one user now means taking it away from another. New

groundwater wells may expand supplies in some regions, but groundwater use will need to be reduced to the level of recharge in others. New dams and river diversions will rarely offer sustainable solutions, because in most cases they entail drawing more water from freshwater systems that are already overtaxed. In fact, the construction of new dams has slowed markedly over the last couple of decades as the public, governments, and financial backers have begun to pay more attention to their high economic, social, and environmental costs. Whereas nearly 1,000 large dams began operation each year from the 1950s through the mid-1970s, the number dropped to about 260 annually during the early 1990s. Even if conditions become more favorable to dam construction, it seems unlikely that new reservoirs built over the next 30 years will increase accessible runoff by more than 10 percent while population is projected to expand by 45 percent during that period.



PROJECTED WATER SAVINGS FROM U.S. EFFICIENCY STANDARDS

Fixture efficiency: The Energy Policy Act of 1992, which sets new water-use standards, is expected to cut total consumption by toilets, faucets, and showerheads by 36 percent over the next 30 years as new water-efficient models of these fixtures replace existing stock.

Another option, desalination, is often held up as the ultimate solution to the world's water problems, since the oceans hold more than 97 percent of the earth's water. As early as 1961, President John F. Kennedy noted that if humanity could find an inexpensive way to obtain freshwater from the seas, the achievement "would really dwarf any other scientific accomplishment."

Some 35 years later, desalination is a proven technology experiencing solid growth. As of December 1995, a total of 11,066 desalting units had been installed or contracted for worldwide, with a collective capacity of 7.4 billion cubic meters per year.

Despite considerable growth, however, desalination still plays a minor part in the global supply picture, accounting for less than 0.2 percent of world water use. Removing salt from water either by heating it and condensing the steam (distillation) or by filtering it through a membrane (reverse osmosis) is highly energy intensive. And although costs have come down to $1.00-$1.60 per cubic meter, desalination remains one of the most expensive supply options. The wealthy countries of Saudi Arabia, United Arab Emirates, and Kuwait—which together encompass only 0.4 percent of world population—accounted for 46 percent of the world's 1993 desalting capacity. These countries are essentially turning oil into water, and they are among the few that can afford to do so. For the foreseeable future, seawater desalination will likely continue to be a lifeline technology for water-scarce, energy-rich countries as well as island nations with no other options. But desalination capacity would have to expand 30-fold to supply even 5 percent of current world water use. As such, the option will likely remain a minor contributor to total water supplies worldwide.

Other options, such as towing icebergs, transporting water by tanker, or shipping it in large bags, may increase drinking water supplies in some specific water-scarce areas, but like desalination, are expensive and not likely to make much of a dent in the global supply picture over the next 30 years.

Cutting Demand

Measures to reduce demand for water through conservation, recycling, and higher efficiency are typically more economical than efforts to gain new supplies of freshwater. Costing between 5 and 50¢ per cubic meter of water, nearly the entire spectrum of conservation options—including leak repair, the adoption of more efficient technologies, and water recycling—cost less than the development of new water sources and much less than desalination.

Unfortunately, large subsidies to water users continue to discourage investments in efficiency and convey the false message that water is abundant and can be wasted—even as rivers are drying up and aquifers are being depleted. Farmers in water-short Tunisia pay 5¢ per cubic meter for irrigation water—one-seventh the cost of supplying it. Jordanian farmers pay less than 3¢ per cubic meter, a small fraction of the water's full cost. And federal subsidies to irrigators in the western United States total at least $20 billion, representing 86 percent of total construction costs of installing the systems, according to Richard Wahl, formerly an economist at the U.S. Department of Interior. Although poverty alleviation and other social goals may justify some degree of irrigation subsidy, especially for poor farmers, the levels of subsidiza-

Although social goals may justify some irrigation subsidies, especially to aid poor farmers, today's low prices are a clear invitation to waste water and thus a major barrier to sustainable use.

tion that exists today is an invitation to waste water.

Experience in the Broadview water district in California, where farmers irrigate 4,000 hectares of melons, tomatoes, cotton, wheat, and alfalfa, reveals the gains an intermediate policy can yield. In the late 1980s, when the district was faced with the need to reduce polluting drainage to the San Joaquin River, it established a tiered water pricing structure. The district determined the average volume of water used over the 1986-88 period and applied a base rate of $16 per acre-foot (1.3¢ per cubic meter) to 90 percent of this amount. Any water used above that level was charged at a rate 2.5 times higher. In 1991, only 7 out of the 47 fields in the district used any water charged at the higher level: the higher price encouraged farmers to switch crops and irrigate more efficiently, thus cutting the average amount of water applied to the district's farms by 19 percent.

Because agriculture accounts for two-thirds of water use worldwide, even small-percentage reductions can free up substantial quantities of water for cities, ecosystems, and additional food production. Farmers in northwest Texas, for example, who have had to cope with falling water tables from depletion of the Ogallala aquifer—an underground water reserve in the region that gets extremely limited recharge from rainfall—have reduced their water use by 20 to 25 percent by adopting more efficient sprinkler technologies, special valves to ensure even water distribution, and other water-saving practices.

Likewise, results from a variety of countries show that farmers who have switched from furrow (trench) systems or sprinkler irrigation to drip systems, which deliver water nearer to the roots of crops, have cut their water use by 30 to 60 percent. Crop yields often increase at the same time because plants are effectively "spoon-fed" the optimal amount of water (and often fertilizer) when they need it. Drip systems, which cost in the range of $1,200 to $2,500 per hectare, tend to be too expensive for most poor farmers and for use on low-value row crops, but research is under way to make them more affordable. Colorado-based International Development Enterprises has developed a drip system that costs just $50 per half acre ($123 per half hectare), 10 to 20 percent of the cost of traditional drip systems. The keys to keeping costs down are simple materials and portability: instead of each row of crops getting its own drip line, a single line is rotated by farmers among ten rows.

Along with encouraging irrigation efficiency improvements, more appropriate water pricing would also promote the treatment and reuse of urban wastewater for irrigation, which is typically more expensive than most conservation and efficiency measures but often less expensive than developing new water sources. Wastewater contains nitrogen and phosphorus, which can be pollutants when released to lakes and rivers but are nutrients when applied to farmland. Moreover, unlike many other water sources, treated wastewater will be both an expanding and fairly reliable supply, since urban water use will likely double by 2025. Many large cities located along coastlines dump their wastewater, treated or untreated, into the ocean, rendering it unavailable for any other purpose and harming coastal marine life. As long as the wastewater stream is free of heavy metals and harmful chemicals, and disease-causing microorganisms are controlled, it can become a vital new supply for irrigating crops.

Adapting to Dryness

Raising the water productivity of the global crop base is also critical. Actual strategies used will vary by crop, climate, and the type of water-control system, but the basic aim will necessarily be the same in each: to optimize the timing and amount of moisture in the root zone and to enhance the crops' ability to use that moisture productively.

Through plant breeding, for example, biologists can hasten the process of plant adaptation to dryness. Studies have shown that if no other factors are limiting plant growth total production is proportional to the amount of water a plant transpires. Larger or deeper root systems that allow plants to take in more moisture can thus increase yield. New genetic techniques are making it possible to screen crop varieties for water-efficiency traits. And developing varieties with shorter growing seasons or the ability to grow in cooler periods, when evaporation and transpiration are lower, could also help improve crops' water-use efficiency.

The International Rice Research Institute in the Philippines, for one, is focusing on developing more efficient irrigation operations, technologies that reduce water consumption, and changes in the rice plant itself to improve water-use efficiency. Breeders have already shortened the maturation time for irrigated rice from 150 days to 110 days, for example, a major water-saving achievement.

Matching crops to varying water quality can also enhance supplies for irrigated agriculture. In the western Negev of Israel, for example, farmers successfully grow cotton using highly salty water from a local saline aquifer. The Israelis have also found that certain crops—such as tomatoes grown for canning or pastes—may actually benefit from somewhat salty irrigation water. The varying salt tolerances of crops raise the possibility of multiple reuse of irrigation water. In California, for instance, moderately salty drainage water from a crop of average salt tolerance is used to irrigate more highly tolerant cotton. In turn, the drainage from the

Hoping to improve the efficiency with which crops use water, biologists are breeding varieties that mature more quickly and can grow during cooler periods, when evaporation and transpiration are lower.

cotton fields, which is even saltier, is used to irrigate salt-loving crops, a number of which scientists have made considerable progress toward commercializing. For example, when a variety of Salicornia, a seed-bearing plant, was irrigated with seawater in a coastal desert near Mexico's Sea of Cortez, its yield was equal to or greater than freshwater oilseed crops such as soybean and sunflower.

Like more realistic water pricing, water marketing can create incentives both to encourage efficiency and reuse, as well as to allocate water more productively. Instead of looking to a new dam or river diversion to get additional water, cities and farmers can purchase supplies from others who are willing to sell, trade, or lease them water or water rights. The Metropolitan Water District of Los Angeles, for example, is investing in conservation measures in southern California's Imperial Irrigation District in exchange for the water those investments will save. The annual cost of the conserved water is estimated at about 10¢ per cubic meter, far lower than the water district's best new-supply option. In Chile, where water policy encourages marketing, water companies that serve expanding cities frequently buy small portions of water rights from farmers, most of whom have gained surpluses through efficiency improvements.

The setting of efficiency standards has also proven to be an effective policy tool for stretching supplies. U.S. legislation passed in late 1992 requires manufacturers of toilets, faucets, and showerheads to meet specified efficiency standards as of January 1994. U.S. residential water use for these three fixtures is expected to drop by more than 35 percent as the more efficient models replace existing stock over the next 30 years.

A number of other governments, including Mexico and the Canadian province of Ontario, have also adopted standards for household plumbing fixtures. The National Community Water Conservation Program in Cairo is working with the Egyptian government to introduce water conservation standards into the plumbing code. Although efficiency standards have so far mainly been applied to household fixtures, they offer potential for water savings in agriculture, industry, and other municipal uses as well.

Further Steps

Here and there, promising efforts inspire hope that the consequences of water shortage can at least be delayed. Yet so far, concerted national and international efforts to bring all the pieces of a sustainable water strategy together are few. One notable exception, however, may be South Africa. In early 1996, the Minister of Water Affairs and Forestry laid out principles for a fundamental overhaul of the nation's water law and management. Among the top priorities are providing each South African with access to at least 25 liters of water a day to meet the minimum need for drinking water and sanitation, pricing water at levels that reflect its value, encouraging water marketing, mandating that water suppliers adopt conservation measures, allocating water to the environment to prevent the loss of ecosystem functions, and reserving water for countries downstream in order to promote regional cooperation and integration.

Although these principles are promising, turning them into actual laws, policies, and actions will not be easy because it will involve dismantling decades of apartheid-era water legislation. Moreover, the country is still pursuing the socially and environmentally destructive Lesotho Highlands Water Development Project, an $8 billion dam-and-diversion scheme aimed at supplying the Johannesburg region with water from the tiny mountain kingdom of Lesotho. Nonetheless, the nation's new water plan, which could be taken up by the parliament in early 1997, may emerge as one of the stronger national water strategies thus far.

Beyond the adoption of similar strategies in other nations, there is also an urgent need at the international level to assess and monitor the availability of water for food production. A basic blueprint for satisfying human and ecological needs as well as using and allocating water more efficiently will not guarantee agriculture the water supplies needed to meet the world's future food demands. For example, many of the policies and strategies to promote more sustainable water use—such as raising water prices and expanding water markets—will likely shift resources away from agriculture toward higher valued uses.

The time may not be far off when a global grain bank will be needed to guard against food shortfalls induced by water shortages. Particularly in Africa, Asia, and the Middle East, water deficits will widen markedly in the coming decades. Together these regions are projected to grow by nearly 2.3 billion people by 2025, accounting for 87 percent of projected population growth over the next 30 years. Many African and Asian countries are unlikely to have the financial resources to balance their water books by purchasing surplus grain on the open market.

Finally, reining in demand for water offers the best hope of preventing scarcity from leading to more hunger, poverty, widespread ecological decline, and social instability. Living within the limits of nature's water supply will require reduced consumption among the more wealthy social groups and smaller family size among all groups.■

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From Here to Eternity

Once translated into digital form, our artifacts can live forever as immutable patterns of numbers. We may come to miss their perishability.



SAMUEL C. FLORMAN

WHEN my local video store recently held a sale of "film classics," I picked up, at a bargain price, a copy of the 1974 movie *Death Wish*. Why would I want to own this chestnut, featuring Charles Bronson as an architect turned vigilante after the murder of his wife and brutalization of his daughter? Because about two-thirds of the way through it there appears on the screen for a full four seconds—possibly five—the picture of a sign with my company's name on it.

This free advertising came as a reward for saving the film production crew from an embarrassing blunder. As we watched a scene being shot in front of our work site, we were amazed to see that an actor playing a construction worker was wearing the wrong kind of hardhat. He had on a flat helmet, reminiscent of a World War I doughboy, rather than the familiar hardhat of today, which is modeled along the lines of World War II headware. (The flat helmet is worn by heavy construction underground workers—the "moles"—but never by building construction workers.) We rushed in to prevent this terrible gaffe, and benevolently provided a hardhat of the proper sort. The grateful director told us to position our five-foot-square company sign as a backdrop for the following take.

The movie's release, about a year later, brought telephone calls from friends and colleagues who had seen it and noticed the sign. It's amazing the impact that can be made by an image that appears on the screen for just a few seconds. (Our favorite call came from a competitor who said that we'd spoiled his evening.) The sudden celebrity was enjoyable but fleeting. Even though the film was a popular success, it was soon gone, and the telephone calls stopped coming. Ah, well: *sic transit gloria mundi*; so passes away the glory of this world.

Or does it? As I watched the film at home on my VCR, I thought anew about the ephemeral nature of things. On my television screen, that sign—writ large in red letters upon a glistening white background—looks as fresh and new as it ever did. In the movies it has been saved from the ravages of time.

And physical preservation, first on film, then on videotape, is just the beginning. *Death Wish* will soon be put into digital form, if it has not been already. As the fiber-optic webbing of the world proceeds apace, more and more of the objects we perceive—including "movies on demand"—will come to us in streams of digits. And when pictures are put into digital form they become, theoretically, everlasting; my company sign could endure through eternity. I say "theoretically" because the physical materials in which the 1's and 0's are embedded will not last forever. We don't really know how well CDs and other digital storage media will withstand the rigors of time; the technologies are too new.

But with digitization, the information can outlive the medium; transferring bits from one disk to another produces a perfect replica of the original. This leads me to speculate that we can preserve our digital patterns into infinity. "Things" are inherently perishable; arrangements of numbers are not. They endure like works of literature or symphony scores or mathematical expressions. Thus they are very different from a painting, a printed photograph, or any other physical artifact that inevitably undergoes some degradation or mutation every time a copy is made.

Just think: as ordinary photography moves into the digital realm—as we replace atoms with bits by recording images in binary code—family albums will last forever. Home videos, unless lost or destroyed, will be eternal too. Our capacity to store them in the microscopic world of silicon chips and magnetic and optical disks is, for all practical purposes, approaching the infinite.

I'm not sure we're ready for such a transformation. In life as we have known it, old photos fade and crumble, and boxes of them, along with albums, slides, and reels of family movies, disintegrate and are eventually discarded. Only a few precious mementos are preserved, perhaps restored, and passed along. The natural world teaches us that death and decay are vital to ecological health. Are there similar social processes that might be vital to communal health? In the digital age nothing need be lost; do we face the prospect of drowning in trivia as the generations succeed each other?

I take about a thousand family and trip photos each year, and accumulate perhaps five hours of videotape. Give me 50 years of this, let me save it all digitally, assume my children and their in-laws do the same, and you have a threefold multiple for each generation. This means that my great-grandchildren will inherit well over a million photos plus 6,000 hours of home movies. If they devote one hour each day for viewing—allowing three seconds to glance at a photo and scanning movies at triple-speed—they will spend nine years examining this material. They will not thank me for this. And they certainly will not have the time to look at *Death Wish*. ■

SAMUEL C. FLORMAN is a civil engineer and the author of several books, including The Existential Pleasures of Engineering, *recently reissued in a new edition. His latest book is* The Introspective Engineer *(St. Martin's Press). His e-mail address is scf97@aol.com.*

PHOTO: L. BARRY HETHERINGTON

Bringing High Tech to Low-Income People

Partnerships between community organizations and businesses are bringing jobs and opportunity to the urban poor.



BENNETT HARRISON

IN Seattle, a nonprofit community-based organization (CBO) employs some of the city's poorest and least-skilled people to manufacture critical components for Boeing using state-of-the-art technology. The country's largest predominantly African-American CBO, based in the heart of Newark, N.J., trains health professionals for world-class companies such as pharmaceutical giant Pfizer Inc. In Silicon Valley, a community job-training operation has won consecutive subcontracts with such electronics giants as Motorola and Hewlett-Packard.

These examples illustrate a promising trend in urban development. Community-based organizations provide the economic and political voice that low-income communities of color lack. They shore up, or substitute for, the family connections and influence with business and political actors that poverty and discrimination have so deeply eroded. In the absence of strong CBOs, the economic revitalization of inner cities that would benefit society as a whole is inconceivable.

Nonprofit training-program operators, small-business owners, and housing developers located in low-income areas have long confronted the day-to-day travails of doing business in neighborhoods that have suffered from years of physical, social, and political neglect. Now new forces are adding to the pressure even as they open up new opportunities. Especially challenging are the devolution of federal money and power to the states and the continuing trend toward privatization of hitherto publicly provided services.

One response lies in forging or joining formal business networks with local technology companies. Subcontracts to supply parts or services to mainstream corporations bring immediate jobs and revenues into inner cities. Over the longer term, participation within the manufacturing "supplier chains" facilitates the technological learning that will help communities compete. And regular interaction with established firms can help give urban developers new private-sector allies—linkages that can pay off not only in job placements for the CBOs' inner-city constituents but also in future political support and financing.

Consider Pioneer Human Services, a Seattle organization that has long provided transitional housing and social services to ex-convicts, parolees, and people with a history of drug and alcohol abuse. Pioneer now owns and operates a high-tech metal-working facility that employs several hundred people and performs contract work for Boeing. At Pioneer, I have seen young ex-offenders held to exacting standards as they operate computer-controlled machine tools to fabricate parts according to designs transmitted electronically from their world-class customer.

Pioneer must be doing something right. The manufacturing operation is bursting at the seams, and last year it became one of fewer than 100 organizations in the state to qualify for ISO-9002 status—certification by the International Standards Organization as a "highly technically qualified" supplier. Pioneer's workers acquire skills in a first-rate production setting that offers the patience and support few conventional businesses can afford. A similar relationship links a prominent African-American development corporation in Detroit—called Focus: Hope—to the big carmakers.

The most successful workforce-development entity is the Center for Employment Training (CET)—a mainly Chicano organization headquartered in San Jose that maintains operations nationwide. CET has managed for more than two decades to train and successfully connect people with meager job prospects—including older displaced workers, single parents on welfare, unskilled farm workers, and immigrants—to leading Silicon Valley companies such as IBM, Hewlett-Packard, and Motorola. Smaller firms have hired CET's trainees as well; such recruits are "carriers" of skills and technical know-how acquired over the years by CET through its relationships with larger companies.

For three years, CET has teamed up with Newark's New Community—the country's largest African-American nonprofit development corporation—to train people to work in health-care occupations. The joint project borrows instructors from organizations throughout northern New Jersey, including Pfizer and the Robert Wood Johnson Foundation, the nation's largest philanthropy devoted exclusively to health and health care. These instructors in turn reach out to colleagues in private hospitals and other firms to make job placements. All 35 of the program's graduates have landed jobs, with starting salaries averaging $21,000.

Such success is especially helpful during the recent downturn in public funding for cities. But even if federal and state governments were to spend more money on urban revitalization, the business alliances that the CBOs are forging would still have great value. These arrangements are proving to be excellent ways to expand the technological capabilities of the grass-roots organizations that are most committed to working with the urban poor. ■

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PHOTO: L. BARRY HETHERINGTON

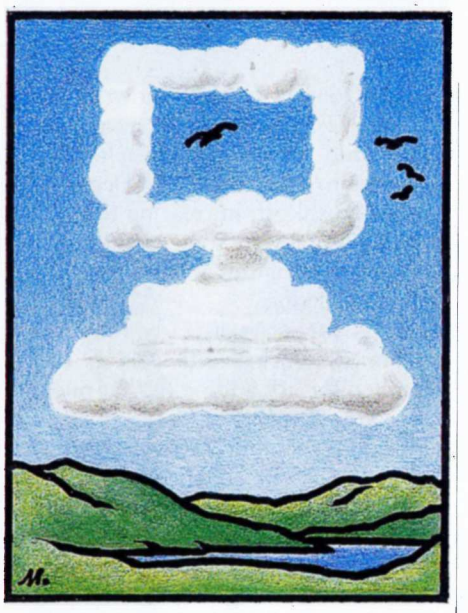
Reviews

BOOKS

LOST IN CYBERSPACE

Escape Velocity: Cyberculture at the End of the Century
by Mark Dery
Grove Press, $23.00

BY ELLEN SPERTUS



MOST books about cyberculture are either rants or raves, heralding the new utopia or dismissing it as utterly dystopian. What they have in common is that they focus on computer technology itself, assuming that it is unlike anything human beings have ever faced. But in *Escape Velocity: Cyberculture at the End of the Century*, Mark Dery takes a different approach. While he acknowledges that the technology is amazing and new, he shows that people's reactions to it actually have less to do with its amazing newness than with basic human drives that have been present for millennia.

Dery begins with a discussion of how the counterculture went from rejecting technology in the sixties to embracing it in the nineties. He cites *Whole Earth Catalogue* founder Stewart Brand's 1972 assertion that hackers had the same worldview as hippies but better technology, and goes on to talk about how altered states are now sought not through drugs but through computerized virtual reality. In the sixties Timothy Leary said, "Turn on, tune in, and drop out"; in the nineties, "Turn on, boot up, and jack in."

From there the author launches into an exploration of the fundamental motives behind such pursuits. He notes, for example, that when cyberians rhapsodize about transferring the mind from the body into an immortal machine, they are arguably describing "techno-transcendentalism's version of born-again Christianity's 'rapture,' in which true believers are lifted out of the mundane, into the parting clouds." In an age when religion has taken a back seat to reason, people's fear of death and their unmet spiritual needs, combined with a simple failure to comprehend new technology, can yield technopaganism. Freud's observation that primitives "believe they can alter the external world by mere thinking" is pertinent here, too: since thought, in the form of computer programs, can profoundly affect reality, it is no wonder that mysticism is on the rise. Even the technological elite are not immune. In *The Soul of New Machine*, Tracy Kidder quotes a programmer on the thrill of assembly language: "I could . . . talk right to the machine I could talk to God."

Using Technology to Protest Technology

One of Dery's deepest concerns is the enormous power of technology. He has no sympathy for starry-eyed cyberians such as *Wired* editor Kevin Kelly, who claims that "technology is absolutely 100 percent positive"; the author's attitude is similar to that of cartoonist Tom Tomorrow, who has made this quotation a caption for an atomic bomb explosion in which one victim explains to the other that any distress experienced "is simply the result of your outmoded 'second wave' thinking." And Dery fears not only the misuse of technology but the potential of techno-utopian fantasies to distract us "from the devastation of nature, the unraveling of the social fabric, and the widening chasm between the technocratic elite and the minimum-wage masses." He notes, too, that much of the freedom technology grants us may be illusory. He invokes theorist Arthur Kroker of Concordia University in Montreal, who writes, "Technology allows the few to dominate the many Technologies are enabling people but at the same time government and industry want to control the technologies that enable the masses."

This outlook has drawn Dery to the cyberpunk movement, which is driven largely by the fear of such government and industry control. With dozens of photographs of cyberpunk art and extensive interpretations and descriptions of written and multimedia works, *Escape Velocity* is an invaluable resource for anyone who wishes to gain some understanding of that seemingly impenetrable world. Perhaps the most meaningful insight is that cyberpunks consistently use technology itself to protest technology.

For example, consider cyberpunk music—"electro-industrial rock with a grungy, sci-fi edge." Characterized by "pile-driver rhythms" that are "rammed home by drum machines or clanged out with the . . . sounds of heavy industry," the songs feature lyrics "hoarsely barked or recited in a future-shocked monotone." Those vocals are also "electronically processed to give them a fuzzy, metallic quality that makes them sound as if they've been synthesized by a computer." And in fact the lyrics are often explicitly about "body loathing, social control, and the fear of being superseded by machines."

The effect of all this can be overwhelming, which, as it turns out, is the intent in many cases. "Hemmed in on all sides by machines, the claustrophobic vocals embody the human condition in technoculture," Dery tells us. To put the matter in a larger context, he calls on musician Genesis P-Orridge, who observes that such developments mark a

ILLUSTRATIONS: BRUCE P. MADDOCKS

real change in the nature of popular music. Until recently, P-Orridge explains, the genre was predominantly based on blues and slavery, part of America's agrarian past; now the historical reference point for a significant strain of pop music is the Industrial Revolution.

Dery is not optimistic about the chances that the cyberpunk movement will effect a change in political consciousness, however. Counterculture activities are almost invariably coopted by the mainstream, he says, and for evidence he offers the commodification of rock music, "once too wild for television" and now "a necessary adjunct of TV's all-pervasive ad." The author also believes that cyberpunks frequently undermine themselves by defining art so loosely as to obscure any distinction between it and real-life events. For instance, he criticizes author Douglas Rushkoff for writing that "a homeless man dragging a cardboard box isn't foraging for shelter, he's engaged in 'social hacking.'" Dery's view is that Rushkoff, in treating the man's struggle as if it were some kind of performance art, trivializes and even condones human suffering.

Bookstores are already filled with polemical works, and Dery is to be thanked for not adding to that pile but instead providing a way of sorting through the situation we find ourselves in. To be sure, he does not provide solutions to the problems he sees. But his plea for society to address them is compelling, and that is a firm step in the right direction. If nothing else, the reader is, at least temporarily, jolted out of the irresponsible and ineffective escapism that makes solutions impossible.■

ELLEN SPERTUS is a doctoral candidate in electrical engineering and computer science at MIT and a visiting scholar at the University of Washington.

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BOOKS

THE VALUE OF HUBBLE

Hubble Vision: Astronomy with the Hubble Telescope
by Carolyn C. Peterson and John C. Brandt
Cambridge University Press, $39.95

BY ROBERT J. CRAWFORD

THE "first light" image from the Hubble telescope was almost universally hailed as the beginning of a new era in astronomy and cosmology. Upon closer scrutiny, however, a team of experts discovered that the photograph—which showed a star cluster over 1,300 light years distant—was poorly focused, a smudged halo of light rather than the tight image they had expected. The result was a first-order public relations disaster: once the darling of science journalists, the Hubble telescope came to embody everything wrong with the federal government's "big science" projects. Critics charged that not only were these massively expensive ventures available mainly to narrow scientific communities but they were a bad investment: the technology was so complex that failures, sometimes catastrophic, were statistically inevitable. The general feeling was that perhaps it was time to return to projects designed for small laboratory settings.

But in *Hubble Vision*, science journalist Carolyn C. Peterson and astronomer John C. Brandt affirm that investment in the Hubble telescope was indeed justified. Granted, the telescope is a dauntingly intricate machine. The authors admit that virtually every major system is operating under some flaw that limits its performance, or, in a few cases, renders multi-million-dollar devices inoperable. The star-cluster image that occasioned such praise and, later, such approbation came by its imperfections through normal wear: a tiny speck of paint that chipped off the cap of a testing device caused a light leak—and hence a crucial mirror was ground with an error of about a micron, or one-millionth of a meter. A flapping solar panel that jiggled the telescope smeared still other images. Moreover, software problems continue to surface, such as the ones that have affected the "fine guidance sensors," which have sometimes focused the telescope on the wrong target. Yet because of the unique capabilities of the telescope's many instruments, the authors point out, we are witnessing advances in virtually every aspect of astronomy, astrophysics, and cosmology.

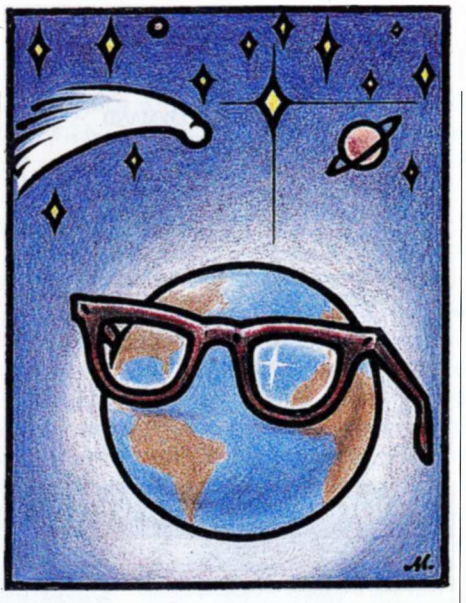
Since the Hubble operates in space, where the filtering effects of earth's atmosphere are not a problem, its "Goddard high-resolution spectrograph," or GHRS, can zero in on ultraviolet radiation emissions in unprecedented detail. And through spectroscopy—a technique that breaks down those emissions into their component wavelengths—researchers can begin to understand the life cycles of heavenly bodies. The reason is that dif-

ferent wavelengths are associated with specific chemical elements, which we know to behave in predictable ways. Beta Pictoris, a star surrounded by elements that appear to be coalescing into planets, is one of hundreds of subjects being studied. Observations of the various elements falling into its core, as well as those forming orbits around it, have enabled astrophysicists to record the stages of a star system's development for the first time. GHRS can even determine the chemical composition of precise regions within Beta Pictoris.

The telescope could also challenge a pivotal notion of its namesake, Edwin Hubble, as astronomers attempt to more accurately define the "Hubble constant"—that is, the rate at which galaxies are receding from one another. Because of its vantage point in space, where, again, there is no atmosphere to complicate matters, the Hubble telescope can greatly refine techniques for measuring galactic distances, and if the refinements turn out to be significant, it would mean that galaxies are receding from one another faster or more slowly than Hubble had thought. And that, in turn, could mean a change in our notion of the age of the universe: a faster rate suggests a younger universe, a slower rate an older one.

Perhaps the most striking discoveries are those that do not quite fit into known science. Peterson and Brandt explore a long roster of such phenomena, including the "chemically peculiar" star Chi Lupi, which exhibits extraordinary concentrations—100,000 times higher than normal—of mercury, gold, and platinum. Some scientists believe that small differences in the radiation coming from the core of the star may create pressures that concentrate these unusual elements on the star's surface. Another hypothesis has to do with the observation that Chi Lupi is part of a "binary system," or two stars that revolve around each other: theoretically, Chi Lupi's gravitational interactions with its binary companion could have exerted the kinds of forces that would bring the elements in question to the fore.

Or take Supernova 1987a, which, as the



Hubble telescope has shown, developed a series of mysterious outer rings years after the explosion responsible for it spread into space. No one knows why, and if this development cannot eventually be explained, it could indicate that the conventional theories through which explanations are being sought are simply inadequate. The outcome could be fundamental revisions in our view of the universe.

Astronomy and Social Values

This is exciting stuff, and it makes for a very convincing case in favor of the Hubble telescope. But the authors' argument would have been stronger if they had not relied so heavily on their write-up of the telescope's findings. For one thing, they would have done well to devote more attention to the quality of the photographic illustrations in the book. While they do provide a few arresting images, such as a shot of the mysterious rings emanating from Supernova 1987a, many of the best photos are credited to *Voyager* or ground-based telescopes.

Also, any broad cross-sectional view of research conducted in a time of explosive advance is bound to leave some things out, and as it happens, *Hubble Vision* leaves out one of the telescope's most interesting contributions: evidence that the number of galaxies in the universe could be 10 times greater than we had previously thought. Scrutinizing Hubble's clearer pictures of what, from the ground, appears to be empty space, astronomers can actually discern additional galaxies that are both far away and in the early stages of formation.

More significantly, the book fails to give due consideration to features that indicate the telescope's larger social value. For instance, Hubble offers an unusual avenue for public participation. Potential observers, whether professionals or not, can apply for time allotments on it through an open peer-review process. Jim Secosky, a high school biology teacher preoccupied with the unexplained brightening of Jupiter's moon Io, was allowed to use the telescope to investigate a hypothesis that evaporation of sulphur dioxide frost was the cause. In making such opportunities available, the Hubble telescope is increasing the participation of both students and amateurs in real-life science.

But even though its case for the telescope could be stronger, *Hubble Vision* will bring a sense of wonder to a wide audience of science enthusiasts. Not only do the authors offer a rich menu of cutting-edge discoveries but they explain scientific issues behind the findings so that lay people can understand them. And in performing this basic service, the book could, finally, help make the debate over big science more meaningful. The kinds of advances Hubble has facilitated result from a research agenda that is well defined yet continually expanding as more information rolls in. The fact is, however, that not all big science projects have such a flexible agenda. A prime example is the superconducting supercollider, whose mission was rigidly circumscribed to "smashing atoms" in search of exotic particles. Reflecting on such matters, the reader soon begins to wonder if we might find a way to establish a clearer criterion of success for big science projects—and once that happens, a bit of subtlety has been restored to the subject. People are, at the very least, no longer thinking strictly in terms of dollars and cents.■

ROBERT J. CRAWFORD is a science writer and research associate at Harvard Business School.

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CONTINUED FROM PAGE 36

during our trip—drew near the ship. Some 80 of these creatures "not only jumped through the air, as they did normally," one passenger recounted. "They did back flips, forward flips, some came leaping straight up into the air. A mother and her calf slid by close to the ship. Clearly they were excited. It was almost as if they were putting on a show, celebrating with us. It was that bizarre."

From our location, the total eclipse had been exactly 32 seconds shy of what the U.S. Naval Observatory stated in a 1955 paper is the theoretical maximum. Still, our time had seemed too short. Consider how Einstein described the basic dilemma. "When you are courting a nice girl, an hour seems like a second," said Einstein of another mystical experience. "When you sit on a red-hot cinder a second seems like an hour. That's relativity."

For the next couple of days, which seemed like a couple of days, not much eclipse talk passed anyone's lips. I was struck with the notion that the event might have affected us too deeply for mere words at the time. We had all been there. Somehow, it would have been foolish to say, "Hey, wasn't that something?" just hours after.

Finally an individual with a unique perspective shared his thoughts about the difficulty of verbalizing such an experience. Harrison Schmitt, an ex-astronaut whose résumé includes a PhD in geology and a stint in the 1970s and '80s as a U.S. senator from New Mexico, compared the eclipse to what he felt when he walked on the moon, the last man to do so, as a member of Apollo 17's crew. "The emotional reaction is indescribable," he said, adding, "The essential element of any meaningful experience is being there." As for the eclipse we had witnessed, he commented, "I wouldn't have missed it for the world."

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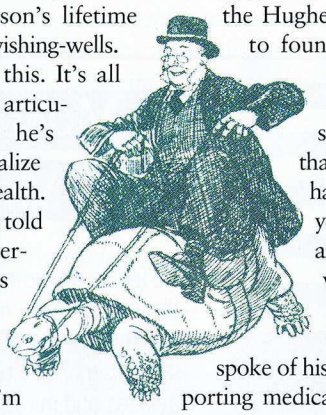
Phenomena

By David Brittan

Waiting for Uncle Bill

The lives of the self-made often follow a symmetrical curve, wherein a mounting acquisitiveness peaks in middle age and mellows into philanthropy as the person grows in wisdom, leisure time, and (perhaps) abhorrence at the thought of his or her heirs driving around in fancy cars. True to form, Andrew Carnegie devoted his youth to building an empire. By his mid-fifties, when he consolidated his holdings into Carnegie Steel, he was thinking seriously about "the improvement of mankind" and declaring that a "man who dies rich dies disgraced." After his retirement in 1901, at age 65, Carnegie went on a giving spree that lasted 18 years and dispatched $350 million. Electronics pioneer David Packard traced a similar curve, setting up a modest foundation in his early fifties and, later, in 1988, when he was 75, enriching it with his $2 billion stake in the Hewlett-Packard Co. There is beauty and logic in this progression: first you inhale, then you exhale. But there is also danger in taking it for granted.

Bill Gates, the president of Microsoft, has adopted this curve as a template for his own financial career, perhaps not realizing what a slippery slope he is on. At 41, he has amassed the largest private fortune in the world—currently $23.9 billion, and probably somewhat larger by the time you finish this paragraph. So far, he has barely stopped to exhale. Gates's charitable expenditures, according to *Time*, consisted of the following as of January: $34 million to the University of Washington, $15 million to Harvard University, $6 million to Stanford, $3 million in book royalties to inner-city libraries, and $200 million in the form of a foundation fund. By ordinary standards, $258 million is a generous sum. But seen as a mere 1 percent of his net worth, Gates's philanthropic record is on a par with the average person's lifetime contribution to wishing-wells.



Gates knows this. It's all part of a plan he articulates whenever he's pressed to rationalize his enormous wealth. "Remember," he told a *Playboy* interviewer three years ago, "95 percent of it I'm just going to give away. . . . I'm saving that for when I'm in my fifties. It's a lot to give away and it's going to take time." Until then, Gates is marshalling his excuses. As he frequently reminds people, his billions are tied up in Microsoft stock. So, presumably, if he wanted to liquidate assets, there'd be phone calls to make, papers to sign. A 1991 *New York Times* profile quoted him as complaining, "I don't have time to figure out what charities make sense," to which he added a postscript that set a new standard for procrastination: "And to the degree Microsoft can do well, it's just that much more to give later."

It is understandable that somebody in the midst of one of the biggest inhalations in the history of capital might regard the future as his to control. The time and resources at his command appear to be infinite, inexhaustible. He will "give later," when he reaches a suitable point on the curve. If only the curve of empire building were so predictable.

At Gates's age, Howard Hughes was a bright young man, too—breaking speed records with his flying and hard at work designing the largest airplane ever built. In his late forties, right on schedule, he turned to philanthropy, using the profits from the Hughes Aircraft Co. to found the Howard Hughes Medical Institute. It seems unlikely that Hughes could have foreseen the years of seclusion and madness that would close out his life. In his waning days he spoke of his interest in supporting medical research, according to James Phelan's *Howard Hughes: The Hidden Years*. "Eventually that is where the bulk of my estate will go," Hughes claimed in an interview. But "eventually" never came: he died intestate, and most of his wealth was divided among his cousins.

The decline of Howard Hughes may be an extreme case, but it is only one of many cautionary tales from which a self-made billionaire might profit. Two of the richest nineteenth-century Americans, John Jacob Astor and Cornelius Vanderbilt, never really got around to major philanthropic works, despite physical and financial longevity. Donald Trump—formerly *the* Donald, now just *a* Donald—found that his chance to make a contribution in proportion to his fortune was cut short by the vicissitudes of the market. The list could go on and on. The point is that anyone who counts on a policy of deferred giving is ignoring the role played by Fortune with a capital "F"—kismet, Lady Luck, destiny.

In an uncertain world, the best insurance policy may be to give it while you've got it. A living testament to this philosophy is Charles Feeney, cofounder of Duty Free Shoppers, Ltd. In 1984, still in his early fifties, he relinquished the chance to become a Billionaire for Life when he signed over most of his wealth—some $500 million—to the charitable fund he founded, Atlantic Foundation and Atlantic Trust. The fund has since mushroomed to $3.5 billion, according to *Newsweek*. Another adherent, Percy Ross, a Minneapolis millionaire, looks for unusual ways to brighten people's lives. He once threw a Christmas Eve dinner for 1,050 disadvantaged children and gave them each a bicycle, for example, and he writes a newspaper column in which he grants readers' requests for money. "I don't need any hospital wings or libraries named after me," Ross told *People* magazine. "I want to enjoy giving my money away while I'm alive."

It's hard to picture Bill Gates handing out bicycles (which, by the way, he could do for every American man, woman, and child). Then again, it's difficult to imagine how *anyone* might spend $24 billion. Gates appears confident that the answer will come to him in due season. As his friend and fellow billionaire Warren Buffett has put it, "He will spend time, at some point, thinking about the impact his philanthropy can have. He is too imaginative to just do conventional gifts." Let us hope that Gates makes up his mind in this lifetime. For when a road is paved only with good intentions, who knows where it might lead?■

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Directs or participates in planning, designing or reviewing plans for erection of structures. Designs structure to meet estimated load requirements. Inspects existing projects & recommends repair, replacement or rebuilding. Advises firm as to economics of proposed construction. Oversees subcontractors. $45,085/yr, 40/wk, Masters degree req'd. No exp. necessary. Must speak Russian. Resume in duplicate to:

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ASTeX is a leading provider of innovative production technology through delivery of components and systems for **semiconductor**, **medical** and **CVD** diamond applications. Our components are used to manufacture the latest generation of advanced memory devices and microprocessors, such as Pentium and PowerPC chips.

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Woburn, MA 01801
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E-mail: jobs@astex.com

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DIRECTOR OF PRODUCT DEVELOPMENT

Seeking Master's or Doctoral level food technologist/food chemist to assist in the development and production of dietary food supplements for our company. Candidate must be familiar with the use of sugar substitutes and fat replacement ingredients in supplements. Will also aid in the creation of new lab space. Please send or FAX your resume to Health-Style USA, Inc., 20 Airport Road, Gilford, NH 03246-6601.

FAX (603) 528-3462.

No phone calls please.

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Renaissance Software is the world's leading provider of Risk Management software for the derivatives market. Our clients include some of the world's largest financial institutions and corporate treasuries.

Our product, OPUS, is a front to back office system for derivatives trading. Using the latest OO technology, under UNIX and NT platforms, it provides applications for pricing the full range of Capital Markets instruments.

The company is based in the heart of Silicon Valley, close to San Francisco, and has offices in New York and London.

As a result of our continued success, we now wish to recruit talented Developers with experience in the following areas:

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All candidates must have degree-level numeracy and candidates with knowledge of finance, specifically risk management, interest rate and foreign exchange instruments, are of particular interest. Strong presentation and communication skills are a pre-requisite for all positions. These are unique opportunities to develop your technical and business skills with what is probably the finest international organization of its kind.

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(415) 941-8943

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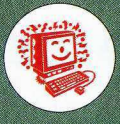
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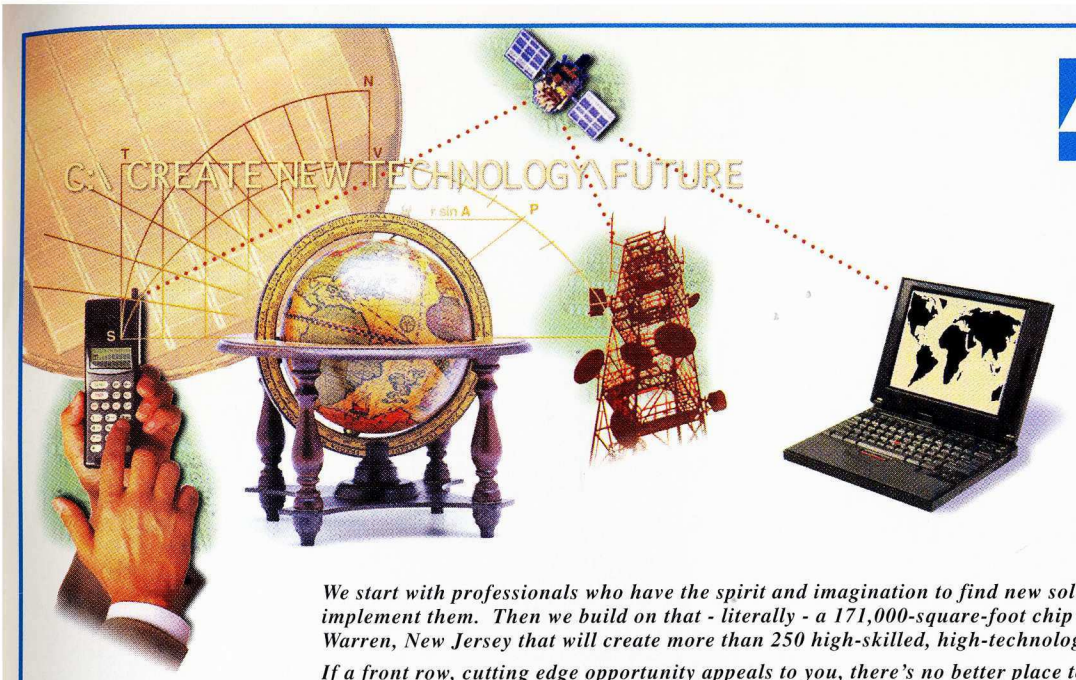
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DESIGN ENGINEER, Advanced GaAs Design

Responsibilities involve RF IC circuit design, including power amplifiers, receivers and bias stabilization; simulation layout and engineering evaluation and device characterization.

BSEE and 2-3 years of experience with RF IC design required.

JOB #96-265/MIT

DEVICE ENGINEER

Electrically characterizes new devices and circuits. Supervises layout, manufacturing and assembly of new device and develops test program for new devices. Evaluates new equipment for processing/device development and testing. Supports the improved M gauge resistivity program used in manufacturing. Conducts technology development for advanced passive components.

BS in Electrical Engineering, Physics or equivalent and at least 5 years of experience assembling and manufacturing power devices required. Must have design experience in power devices, specifically GaAs FETS. Background in device physics, processing, modeling and thermal design essential.

JOB #95-72/MIT

SENIOR DESIGN ENGINEER

Independently designs and develops new IC products to volume production. Duties include electrical, mechanical layout packaging and assembly design. Products include Fiber Optic MMICs, linear MMIC amplifiers, clock recovery ICs, etc.

BSEE and at least 5 years of directly related experience with GaAs or RF MMIC design required. Must have broad background with characterization and applications of ICs for RF and Microwave, as well as experience with GaAs MMIC design, fiber optic systems/components and clock recovery circuit design(PLL). Will need to work independently and with minimal supervision, train engineers and technicians and have knowledge of personal computers for design and test applications. Having supervised small design engineer team is a plus. Some travel required.

JOB #96-178/MIT

SENIOR DESIGN ENGINEER

Independently designs and develops new RF IC products to volume production. Duties include electrical, mechanical layout, packaging and assembly design. Characterizes, models and analyzes devices such as FETs, diodes and passive components. Designs and purchases test fixtures and setups. Provides customer support on technical matters.

BSEE required, MSEE or higher a plus. Must have 5 years of directly related experience and broad background in characterization and applications of ICs for RF and Microwave. Will need to work independently with minimal supervision and train other engineers/technicians.

JOB #96-280/MIT

SIMULATION SUPPORT ENGINEER

Coordinates future releases of IC design tools for all engineering; maintains up-to-date model libraries for IC design tools; evaluates new tool sets; assists users of IC design tools and develops software to improve IC design process.

B.S. in Electrical Engineering, Physics or equivalent and at least 2-3 years of experience in integrated circuit design and device modeling are required. Familiarity with circuit simulation tools and schematic capture required, Commercial CAD (HSPICF, LIBRA, PSPICF, SPECIRE) a plus. Will need software and PC development skills.

JOB #97-24/MIT

TEST ENGINEER

Designs, builds and maintains RF/Microwave Rack and Stack Test Systems; writes, compiles, debugs and documents production test and probe programs; generates schematics, drawings and equipment specifications as needed and provides guidance for test technician on system troubleshooting and repairs.

Must have RF/Microwave knowledge and 3+ years of experience. Exposure to PC/Automated testing required. Knowledge of Visual Basic/Basic Programming and RF/Microwave test equipment essential.

JOB #96-146/MIT

GaAs I PROCESS ENGINEER

Characterizes GaAs wafer properties, IC device characteristics and processing for GaAs MMICs in expanding manufacturing facility.

BS degree and MS with at least 5 years experience in semi conductor processing required. GaAs background a plus.

JOB #96-212/MIT

PRODUCT ENGINEERS

Monitors yield, analyses, summarizes and provides corrective action for electrical or visual failures. Designs experiments, Fab through life test, to improve processes for higher yield products; determines lot wafer/dispositioning; verifies quality final test and calibration.

BSEE required. Must have at least 5 years of experience or similar technical background. Will also need basic knowledge of semiconductor fabrication, testing and packaging.

JOB #96-198/MIT

CMOS DESIGN MANAGER

To launch our development effort, you must have at least 10 years in designing analog/mixed signal CMOS ICs, including OP AMPS, A/D D/A converters and CODECS ISDN line interface circuits. 5 years of experience in leading a group of circuit designers is also required. MSEE or equivalent necessary. Strong interpersonal skills essential.

JOB #96-51/MIT

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